MOD. 03 EXTENDS PERIOD OF PERFORMANCE THROUGH 9/30/91.
NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 03/23/92

Project No. E-27-637___________ Center No. R663-0A0_________

Project Director JAYARAMAN S___________ School/Lab TEXT ENGR____

Sponsor US DEPT OF DEFENSE/DEFENSE LOGISTICS AGY________________

Contract/Grant No. DLA900-87-D-0018-0003_______ Contract Entity GTRC

Prime Contract No. ______________________________

Title ANALYSIS OF DEFECTS IN TROUSER MANUF. & DEVELOP. OF A KNOWLEDGE-BASED FRA

Effective Completion Date 910930 (Performance) 911231 (Reports)

Closeout Actions Required: Y/N Date Submitted

Final Invoice or Copy of Final Invoice Y _____
Final Report of Inventions and/or Subcontracts Y _____
Government Property Inventory & Related Certificate Y _____
Classified Material Certificate N _____
Release and Assignment Y _____
Other ____________________________ N _____

Comments________________________________________________________________________ __

Subproject Under Main Project No. ____________

Continues Project No. _________________

Distribution Required:

Y
Y
Y
Y
N
Y
Y
Y
N
N

Project Director
Administrative Network Representative
GTRI Accounting/Grants and Contracts
Procurement/Supply Services
Research Property Management
Research Security Services
Reports Coordinator (OCA)
GTRC
Project File
Other ____________________________

NOTE: Final Patent Questionnaire sent to PDPI.
GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT (SUBPROJECTS)

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Center No.</th>
<th>Project Director</th>
<th>School/Lab</th>
<th>Sponsor</th>
<th>Start</th>
<th>End</th>
<th>Funded</th>
<th>Contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-27-637</td>
<td>R6638-0A0</td>
<td>JAYARAMAN S</td>
<td>TEXT ENGR</td>
<td>US DEPT OF DEFENSE/DEFENSE LOGISTICS AGY</td>
<td>881101</td>
<td>910930</td>
<td>59,173.00</td>
<td>59,173.00</td>
</tr>
</tbody>
</table>

LEGEND
1. * indicates the project is a subproject.
2. I indicates the project is active and being updated.
3. A indicates the project is currently active.
4. T indicates the project has been terminated.
5. R indicates a terminated project that is being modified.
SOFTWARE DEVELOPMENT PLAN/TECHNICAL REPORT
APPAREL MANUFACTURING TECHNOLOGY CENTER
SHORT TERM RESEARCH PROJECTS

DLA900-87-D-0018-0001
DLA900-87-D-0018-0002
DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 881201 - 881231

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

January 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

December Activities

Researchers held a meeting with the Quality Control Manager of Oxford Slacks to discuss his possible involvement in the project.

A graduate research assistant was selected and has joined the project team.

DPSC provided defects analysis information to the AMTC team. A study of this data led to a preliminary estimate of the distribution of the types of defects in utility trousers.

A questionnaire is being developed to send to apparel manufacturers. This tool will assess the financial ramifications of defects as well as the different types of defects currently experienced in the apparel industry.

Review of literature in the area of fabric and apparel defects was begun.

Plans for January

Complete work on the initial version of the questionnaire and test its validity by mailing to a sample group of companies.

Continue literature review.

Identify companies for participation in the research effort.
SOFTWARE DEVELOPMENT PLAN/TECHNICAL REPORT
APPAREL MANUFACTURING TECHNOLOGY CENTER
SHORT TERM RESEARCH PROJECTS

DLA900-87-D-0018-0001
DLA900-87-D-0018-0002
DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890101 - 890131

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

February 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

January Activities

Dr. Krishna Parachuru made a two-day visit to N.C. State and collected technical information on fabric and sewing defects in general, and defects in trouser manufacturing in particular. He discussed the project with Dr. Peyton Hudson and Dr. Trevor Little. Dr. Parachuru also made several visits to Oxford Slacks, spending time in the sewing and pressing departments to obtain an initial background on the range and extent of defects encountered in trouser manufacturing. He also analyzed in-house quality control procedures, obtained information on the classification of defects and allowable tolerances in the sewing department, and general guidelines issued to shop floor workers in the sewing and pressing departments.

A questionnaire for collecting information on trouser defects has been developed. GTRI researchers are modifying the final document which will be distributed to AMTC Steering Committee members during February.

Plans for February

Complete work on the final version of the questionnaire and test its validity by mailing to Steering Committee members.

Continue collection of literature related to garment defects and the establishment of knowledge-based expert systems.

Initiate classification and structuring of available information on garment defects.

Establish working contact with select group of apparel quality control experts.
SOFTWARE DEVELOPMENT PLAN/TECHNICAL REPORT
APPAREL MANUFACTURING TECHNOLOGY CENTER
SHORT TERM RESEARCH PROJECTS

DLA900-87-D-0018-0001
DLA900-87-D-0018-0002
DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 881201 - 881231

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

January 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
February Activities

At AMTC's Annual Contract Briefing, Sundaresan reviewed the project's status with Don O'Brien, Dan Gearing, and Helen Kerlin.

Dr. Phiroze Dastoor joined the research team. He is involved in establishing a network in the research room and installing the software for use on the project. The second Sun 386i workstation has also been received and installed.

Dr. Dastoor and Dr. Krishna Parachuru visited Oxford Slacks and met with the Sewing and Pressing Superintendents. The discussions centered around the origin of fabric and sewing defects and their classification at the final inspection stage.

The questionnaire has been finalized and mailed to AMTC Steering Committee members. The team is awaiting feedback.

Work on the classification and structuring of available information on garment defects has been initiated.

Plans for March

Complete telephone/written questionnaire responses of the Steering Committee members.

Continue collection of literature related to garment defects and the establishment of knowledge-based expert systems.

Establish working contact with select group of apparel quality control experts.

Dr. Krishna Parachuru will attend the Annual Meeting of the ASQC to be held in New Orleans. He will discuss the research effort and secure participation of quality control experts.
SOFTWARE DEVELOPMENT PLAN/TECHNICAL REPORT
APPAREL MANUFACTURING TECHNOLOGY CENTER
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

DLA900-87-D-0018-0003
(E-27-637)

PERFORMANCE PERIOD: 890301 - 890331

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

April 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.

CLIN 0010
Contract Data Requirements List Item A001
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

March Activities

Researchers visited Dowling Textiles Manufacturing Company and Oxford Slacks to continue discussions with industry regarding the origin of fabric and sewing defects and their classification at the final inspection stage. Meetings with Quality Control personnel were held to understand general quality control procedures in the industry and to learn more about potential defects in the spreading and cutting operations.

Dr. Krishna Parachuru participated in the American Society of Quality Control (Needle Trades Division) annual meeting in New Orleans. Dr. Parachuru met some well known quality control experts in the textile/apparel industry and obtained their views on the defects project. Mr. Jerry Duncan, chairman of ASQC’s Needle Trades Division, briefed the meeting attendees on three of AMTC’s research projects. Copies of the defects questionnaire were distributed to all interested participants.

Feedback from the Steering Committee questionnaire is being received and evaluated.

Work on the classification and structuring of available information on garment defects is continuing.

Dr. Dastoor installed a local-area network consisting of Sun and DEC computers. The network will be used for the architecture, procurement, and defects projects.

Dr. Dastoor is also reviewing defects literature collected from government, industry and academic sources. This evaluation is a prerequisite for the establishment of experts systems.

The team is in the process of assembling a panel of apparel quality control experts to provide direction on the project.

Plans for April

Complete analysis of questionnaire responses of the Steering Committee members and ASQC members.

Make an initial assessment of the economic impact of defects based on the information obtained from the questionnaire and other sources.

Make follow-up calls to ASQC quality control experts and seek further involvement in the project.

Continue collection of literature and structuring of available information on defects.
PROGRAM SCHEDULE

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890301 - 890331

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

April 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEPARTMENT OF DEFENSE, AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
| PHASE 1 | Knowledge Base Development | Literature Review & Selection of Experts | Economic Impact of defects | Classification of defects | Structuring of knowledge | Establishing origins of defects | Identifying remedies of defects | Technical Report |
| PHASE II | Analysis & Software Development | Develop and mail questionnaire | Analyze questionnaire responses | Implement in software | Industry-wide economic impact | Develop software manual | Debug/field-test software | Gather data for other garments | Technical Report |
| PHASE III | Refinement & Knowledge Base Extension | Complete software development | Complete software manual | Develop training program | Complete extended defects knowledge base (other garments) | Analyze Choice of methodology | Final Report & Demonstrate Software Product |

**ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE**

**PERFORMANCE PERIOD:** 030189 - 033189
SOFTWARE DEVELOPMENT PLAN
AND TECHNICAL REPORT

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003
(E-27-637)

PERFORMANCE PERIOD: 890401 - 890430

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

May 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

April Activities

Researchers visited Swift Textiles in Columbus, Georgia. Swift’s success in the denim market is due in part to the advanced equipment and technology applied to the denim manufacturing process. Executives at Swift agreed to cooperate with Georgia Tech researchers by supplying fabric samples containing the whole range of weaving and finishing defects. Swift will also provide information on the causes and remedies of the most common defects.

Six questionnaires have been received from the AMTC Steering Committee. Based on this feedback, it was decided to develop an additional questionnaire to determine specific details on the economic impact of defects. This new questionnaire as well as the original one are being mailed to members of the AMTC coalition and other selected trouser manufacturers.

Dr. Parachuru met with Aulma Farley, former President of ASQC, and Steven Loftin, Director of Quality Assurance, William Carter Company. Both Farley and Loftin will provide input via questionnaires.

The representational components for basing future software development have been selected. Neuron Data’s Nexpert Object will be the primary implementational vehicle, responsible for all heuristic expression and the diagnostic/analytic schemes. Nexpert is a versatile "expert system shell" combining both rule-based and object-based representations.

Procedural work, interfacing with the operating system and/or with other programs (such as databases) will be handled in C language. Data/control communication tasks between Nexpert and C will be managed by Nexpert’s callable interface; other communication programs/routines will be written if necessary. Both software vehicles are easily portable to the delivery environment.

Work on the classification and structuring of information was also in progress during April.

Plans for May

Make at least two trips to Swift Textiles to learn more about weaving and finishing defects as applied to denim fabrics.

Continue analyzing industry questionnaires.

Continue classification and structuring of available information on defects so that the entire subject matter assumes a logical order and is ready for implementation in the expert
Begin consideration on the structure and format of the proposed diagnostic Nexpert system.

Problems Encountered

The analysis of the economic impact of defects has been affected by the AMTC Steering Committee's slow response to the questionnaire. Therefore, efforts are being directed at classifying the defects and mailing questionnaires to other groups.
PROGRAM SCHEDULE

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890401 - 890430

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

May 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

**PROGRAM SCHEDULE**

**PERFORMANCE PERIOD:** 040189 - 043089
SOFTWARE DEVELOPMENT PLAN
AND TECHNICAL REPORT

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003
PERFORMANCE PERIOD: 890501 - 890531

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

June 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING  
PHASE I: KNOWLEDGE BASE DEVELOPMENT

May Activities

Researchers visited Swift Textiles and met with supervisors in the weaving, finishing and quality control departments. Discussions centered around the technical aspects of defects encountered in weaving, preparatory weaving and finishing processes. The guidelines used for the classification and grading of defects and the overall quality control procedures were also discussed. The visit helped the team to obtain a first-hand knowledge of the defects associated with the manufacture of medium and heavy weight denim fabrics.

Sundaresan distributed questionnaires to the members of AAMA’s Government Contracts Committee.

The research team also took steps to modify the questionnaires so they can be used by a wider audience. Modified questionnaires will be sent to apparel companies not yet contacted.

An initial outline of the structure and format of the proposed expert system has been prepared. The selected knowledge-based system tool (Nexpert-Object) is currently being used to present a first prototype object/class model for textile structures up to and including utility apparel fabrics. It is anticipated that the knowledge-based reasoning of defect occurrences (and their possible causes and remedies) will be superimposed on these fundamental descriptions of the textile/apparel domain. Similar work in fault diagnostics in other areas of engineering/technology is being reviewed for use in software design.

Work on collection, classification and structuring of information related to defects and their origin continued during the month.

Plans for June

Visit Tennessee Apparel to discuss the special problems, if any, encountered by the company in the cutting and sewing of military apparel fabrics.

Conduct discussions within and outside the research team to determine the final structure and format of the proposed expert system.

Think about ways in which pictorial representation of individual defects as a part of the diagnostic software can be accomplished.

Continue discussions with the technical team of Swift Textiles so that a complete understanding of fabric defects as applied to denim fabrics can be obtained.
Continue classification and structuring of available information related to fabric and apparel defects.

**Problems Encountered**

Due to slow initial response to the industry questionnaire, efforts are continuing to identify other apparel groups for mailing questionnaires.
PROGRAM SCHEDULE

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890501 - 890531

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

June 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PROGRAM SCHEDULE

PHASE I
Knowledge Base Development
- Literature Review & Selection of Experts
- Economic Impact of defects
- Classification of defects
- Structuring of knowledge
- Establishing origins of defects
- Identifying remedies of defects
- Technical Report

PHASE II
Analysis & Software Development
- Develop and mail questionnaire
- Analyze questionnaire responses
- Implement in software
- Industry-wide economic impact
- Develop software manual
- Debug/field-test software
- Gather data for other garments
- Technical Report

PHASE III
Refinement & Knowledge Base Extension
- Complete software development
- Complete software manual
- Develop training program
- Complete extended defects
- Knowledge base (other garments)
- Analyze Choice of methodology
- Final Report & Demonstrate Software Product
This project is aimed at developing an expert system to identify sources of various types of defects (e.g., fabric, sewing) and the remedies for minimizing them. Researchers are developing the criteria and rules for classifying and preventing defects. Another goal is to assess the economic impact of defects in apparel manufacturing, such as lost sales due to second quality garments and lost production time due to reworking.

This report documents monthly progress for developing knowledge base software and user documentation materials.
SOFTWARE DEVELOPMENT PLAN
AND TECHNICAL REPORT
APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890601 - 890630

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

July 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
June Activities

Dr. Dastoor and Dr. Parachkuru visited Tennessee Apparel Corporation to gather information about special problems associated with the manufacture of military garments, and to study the inspection procedures to meet DLA’s quality requirements. At the conclusion of the visit, a group meeting was held with top executives of the company. The meeting resulted in a two-way exchanges of views on some of the quality and production problems associated with the manufacture of navy jumper suits, gore-tex camouflage trousers and dress pants. The impact of UPS on product quality and process efficiency was also a major topic during the discussions.

Researchers have fit all possible finished fabric defects into a hierarchical structure and created truth tables to uniquely identify and confirm the presence of individual defects. Structuring of defects and creation of truth tables are initial steps in the implementation of fabric defects. Further refinement of the above steps and the accompanying rules will be made as implementation progresses.

Hierarchical listing of defects in the apparel manufacturing process was begun in June. Information collected from different sources is being used to develop the list. The standard manufacturing flow given in MIL-STD 87062A is being used as a reference for the listing of apparel defects. As in the case of fabric defects, the next step will be the creation of truth tables for unique characterization of each apparel manufacturing defect.

Plans for July

Visit Coastal Industries to observe the manufacture of utility denim trousers.

Begin a two-month software implementation/test cycle for finished fabric defects using the hierarchical listing and the truth tables. This first implementation cycle will serve as a test-bed for current ideas of the research team on the architecture of the proposed expert system.

Complete the listing of apparel defects. Begin work on the truth tables.

Begin listing of defects associated with finishing, packing and shipping processes.

Problems Encountered

Swift Textiles has recently advised researchers that the firm cannot supply representative samples to illustrate spinning, yarn dyeing, preparatory weaving and weaving defects. However, the company will share information on the causes of defects.
Pictorial representation of defects has been temporarily postponed due to logistic difficulties. This will be taken up as soon as the basic structure of the software is fully established.
PROGRAM SCHEDULE

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890601 - 890630

Submitted By:

Susan Griffin

Economic Development Laboratory

Georgia Tech Research Institute

Georgia Institute of Technology

July 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE

DEFENSE LOGISTICS AGENCY
<table>
<thead>
<tr>
<th>PHASE I</th>
<th>Knowledge Base Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature Review &amp; Selection of Experts</td>
<td></td>
</tr>
<tr>
<td>Economic Impact of defects</td>
<td></td>
</tr>
<tr>
<td>Classification of defects</td>
<td></td>
</tr>
<tr>
<td>Structuring of knowledge</td>
<td></td>
</tr>
<tr>
<td>Establishing origins of defects</td>
<td></td>
</tr>
<tr>
<td>Identifying remedies of defects</td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>Analysis &amp; Software Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop and mail questionnaire</td>
<td></td>
</tr>
<tr>
<td>Analyze questionnaire responses</td>
<td></td>
</tr>
<tr>
<td>Implement in software</td>
<td></td>
</tr>
<tr>
<td>Industry-wide economic impact</td>
<td></td>
</tr>
<tr>
<td>Develop software manual</td>
<td></td>
</tr>
<tr>
<td>Debug/field-test software</td>
<td></td>
</tr>
<tr>
<td>Gather data for other garments</td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>Refinement &amp; Knowledge Base Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete software development</td>
<td></td>
</tr>
<tr>
<td>Complete software manual</td>
<td></td>
</tr>
<tr>
<td>Develop training program</td>
<td></td>
</tr>
<tr>
<td>Complete extended defects</td>
<td></td>
</tr>
<tr>
<td>Knowledge base (other garments)</td>
<td></td>
</tr>
<tr>
<td>Analyze Choice of methodology</td>
<td></td>
</tr>
<tr>
<td>Final Report &amp; Demonstrate Software Product</td>
<td></td>
</tr>
</tbody>
</table>

ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERFORMANCE PERIOD: 060189 - 063089
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

This project is aimed at developing an expert system to identify sources of various types of defects (e.g., fabric, sewing) and the remedies for minimizing them. Researchers are developing the criteria and rules for classifying and preventing defects. Another goal is to assess the economic impact of defects in apparel manufacturing, such as lost sales due to second-quality garments and lost production time due to reworking.

This report documents monthly progress for developing knowledge base software and user documentation materials.
SOFTWARE DEVELOPMENT PLAN

AND TECHNICAL REPORT

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890701 - 890731

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

August 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE

DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

July Activities

The major highlights of this month's activities are:

Hierarchical listing of the apparel manufacturing defects has been completed. A few additions to the above list may become necessary as and when additional information is obtained from industry and other sources. The defects covered in the above list are now to be expressed in tables, as per the methodology followed for finished fabric defects.

Software implementation cycle for the finished fabric defects has progressed smoothly after initiation. The first phase of implementation of the finished fabric defects is likely to be complete by the end of September, 89. Thereafter, the software will be tested and scrutinized internally and whatever changes that may become necessary for trouble free operation will be introduced.

Considerable amount of time was spent by the research team, discussing how exactly the system should be designed and built so that it could be used with advantage not only by the apparel manufacturer but also by manufacturers of griege and finished fabrics. It was felt that in order to be effective, the system should have the knowledge and expertise for quality monitoring at four different stages - output stage of griege and finished fabrics, spreading and cutting stage and finished garment inspection stage. It might be possible to design a single system which would enable the quality inspector of finished garments to by-pass the diagnostics software that corresponds to the other three stages of quality monitoring.

The ways and means of accommodating variations in the sewing process sequence permitted by the military specifications have also been considered. Additional flexibility of the system in terms of accommodating other commercial style utility and dress trousers has also been considered at length.

Sundaresan has finalized the arrangements with Mr. Fred Shippee of AAMA for mailing the contractor evaluation questionnaire under the auspices of AAMA to about 500 members. Mr. Shippee and AAMA deserve thanks for their support of the research endeavors.

Plans for August

Proceed with the software implementation of the first prototype for finished fabric defects.

Begin listing of defects associated with finishing, packing and shipping processes.

Schedule a visit to Coastal Industries which makes utility trousers.

Problems Encountered

The visit to Coastal Industries had to be postponed due to schedule conflicts.
PROGRAM SCHEDULE

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890701 - 890731

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology
August 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERFORMANCE PERIOD: 070189 - 073189
SOFTWARE DEVELOPMENT PLAN

AND TECHNICAL REPORT

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890801 - 890831

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

September 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
August Activities

Software implementation for the analysis of finished fabric defects continued during the month; the first prototype is expected in the next few weeks. The final list of finished fabric defects and the corresponding truth tables have been reviewed from the perspective of a finished fabric inspector. This, in turn, highlighted the need for the inclusion of a few additional problems (defects) that become known at the stage of finished fabric inspection or at the spreading and cutting stage.

The list of apparel manufacturing defects compiled earlier has been expanded considerably with the help of the information received from the apparel industry through the questionnaires. Initiation of the review process became a necessity because of the richness and value of the information received.

The individual assembly steps in the sewing process where variations in the process sequence are permitted by the military specifications have been identified. The pros and cons of adopting non-standard process sequences that fall within the scope of the military specification have also been analyzed. It has been recognized that minor variations in the sewing sequence may not cause any major defects or process problems. However, the analysis revealed the possibility of a few unique problems in terms of garment dimensions, puckering, etc. that could arise as a result of variations in the sewing sequence. It was felt that the system should have the capability to identify and trace these unique problems.

In order to make the system useful for all the trouser manufacturers, technical information received from a few well known manufacturers of commercial style utility and dress trousers has been drafted into the list of fabric and sewing defects. It is believed that this inclusion makes the system more flexible.

Problems Encountered

The visit to Coastal Industries has been postponed due to factors beyond the control of the project team.

Some minor implementational problems have arisen due to peculiarities in the operation of the software vehicle, Nexpert. It is hoped that most of the problems encountered will be solved, or worked around.

Plans for September

Continue software implementation for finished fabric defects. Try to come up with the first prototype by the end of the month.

Continue expansion and modification of the hierarchical listing of sewing defects.

Begin listing of defects associated with finishing, packaging, and shipping processes.

Explore the possibility of obtaining representative samples to highlight the whole range of fabric and apparel defects. Seek the cooperation of a few selected manufacturers of denim cloth and denim trousers.
PROGRAM SCHEDULE

APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 890801 - 890831

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

September 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY
# Analysis of Defects in Trouser Manufacturing

## Program Schedule

**Performance Period**: 080189 - 083189

<table>
<thead>
<tr>
<th>Month</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase I</strong></td>
<td>Knowledge Base Development</td>
<td>Literature Review &amp; Selection of Experts</td>
<td>Economic Impact of defects</td>
<td>Classification of defects</td>
<td>Structuring of knowledge</td>
<td>Establishing origins of defects</td>
<td>Identifying remedies of defects</td>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phase II</strong></td>
<td>Analysis &amp; Software Development</td>
<td>Develop and mail questionnaire</td>
<td>Analyze questionnaire responses</td>
<td>Implement in software</td>
<td>Industry-wide economic impact</td>
<td>Develop software manual</td>
<td>Debug/field-test software</td>
<td>Gather data for other garments</td>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phase III</strong></td>
<td>Refinement &amp; Knowledge Base Extension</td>
<td>Complete software development</td>
<td>Complete software manual</td>
<td>Develop training program</td>
<td>Complete extended defects</td>
<td>Knowledge base (other garments)</td>
<td>Analyze Choice of methodology</td>
<td>Final Report &amp; Demonstrate Software Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Analysis of Defects in Trouser Manufacturing
January 13, 1989

Mr. Dan Gearing
Defense Logistics Agency
COTR
ATTN: DPMSO
Cameron Station
Alexandria, Virginia 22304-6100

SUBJECT: Program Schedule/A001 & Data Accession List/A006
Technical Report/A004
Contract Number: DLA900-87-D-0018
Performance Period: 881201 - 881231

Dear Mr. Gearing:

Please find the captioned reports for your review.

Cordially,

Susan Griffin
Associate Project Director
Apparel Manufacturing Technology Center

Attachments
mro

cc: John Adams, Project Director
    Sara Williams, CO
PROGRAM SCHEDULE

GENERIC ARCHITECTURE FOR APPAREL MANUFACTURING

CONTRACT NUMBER: DLA900-87-D-0018-0001

PERFORMANCE PERIOD: 881201 - 881231

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

January 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
### Phase I: Function Architecture
- Review Industrial Practices
- Develop Functional Architecture Specifications
- Build Model and Document

### Phase II: Information Architecture
- Study Information in Industry
- Develop Hierarchical Info. Flow
- Develop Information Architecture Specifications
- Build Model and Document

### Phase III: Dynamics Architecture
- Construct "What If" Scenarios
- Analyze Information Transfer
- Develop Dynamics Arch. and Simulate & Doc. Model
- Develop Generic Apparel Arch.

**Architecture for the Apparel Manufacturing Industry Program Schedule**

**Performance Period:** 881201 - 881231
PROGRAM SCHEDULE

KNOWLEDGE BASED FRAMEWORK FOR TROUSER PROCUREMENT

CONTRACT NUMBER: DLA900-87-D-0018-0002

PERFORMANCE PERIOD: 881201 - 881231

Submitted By:

Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

January 15, 1989

Sponsored By:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review Past Research Efforts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop &amp; Refine Ind. Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collect Info. Through Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyze Results of Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Structured Rep. of Current Practice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Additional Factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interact Findings with Industry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Ranking Scheme</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation: Programming, Debugging, Manual Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Testing and Refinement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report and Installation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KNOWLEDGE-BASED FRAMEWORK FOR TROUSER PROCUREMENT
PROGRAM SCHEDULE

PERFORMANCE PERIOD: 881201 - 881231
PROGRAM SCHEDULE
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

CONTRACT NUMBER: DLA900-87-D-0018-0003

PERFORMANCE PERIOD: 881201 - 881231

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

January 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
**PHASE I**

Knowledge Base Development
- Literature Review &
- Selection of Experts
- Economic Impact of defects
- Classification of defects
- Structuring of knowledge
- Establishing origins of defects
- Identifying remedies of defects
- Technical Report

**PHASE II**

Analysis & Software Development
- Develop and mail questionnaire
- Analyze questionnaire responses
- Implement in software
- Industry-wide economic impact
- Develop software manual
- Debug/field-test software
- Gather data for other garments
- Technical Report

**PHASE III**

Refinement & Knowledge Base Extension
- Complete software development
- Complete software manual
- Develop training program
- Complete extended defects
- knowledge base (other garments)
- Analyze Choice of methodology
- Final Report & Demonstrate Software Product

**PROGRAM SCHEDULE**

**AAMD KNOWLEDGE BASED FRAMEWORK FOR DEFECT ANALYSIS**

**PERFORMANCE PERIOD: 881201 - 881231**
PROGRAM SCHEDULE
APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018-0003
PERFORMANCE PERIOD: 890101 - 890131

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

February 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.

CLIN 0010
Contract Data Requirements List Item A001
PHASE I
Knowledge Base Development
- Literature Review & Selection of Experts
- Economic Impact of defects
- Classification of defects
- Structuring of knowledge
- Establishing origins of defects
- Identifying remedies of defects
- Technical Report

PHASE II
Analysis & Software Development
- Develop and mail questionnaire
- Analyze questionnaire responses
- Implement in software
- Industry-wide economic impact
- Develop software manual
- Debug/field-test software
- Gather data for other garments
- Technical Report

PHASE III
Refinement & Knowledge Base Extension
- Complete software development
- Complete software manual
- Develop training program
- Complete extended defects knowledge base (other garments)
- Analyze Choice of methodology
- Final Report & Demonstrate Software Product

ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERFORMANCE PERIOD: 010189 - 013189
March 14, 1989

Ms. Sara Williams  
Defense Electronics Supply Center  
CO  
ATTN: PSC  
1507 Wilmington Pike  
Dayton, Ohio  45444-5208

SUBJECT: Program Schedules/Technical Reports/  
Contract No. DLA900-87-D-0018 Short Term Research Projects  
Performance Period: 890201 - 890228

Dear Ms. Williams:

Please find the captioned reports attached for your review.

Sincerely,

Associate Director  
AMTC

Attachments

cc: John Adams, PO  
    Dan Gearing, COTR
PROGRAM SCHEDULE
APPAREL MANUFACTURING TECHNOLOGY CENTER
SHORT TERM RESEARCH PROJECT
PERFORMANCE PERIOD: 890201 - 890228

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

March 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
<table>
<thead>
<tr>
<th>PHASE I</th>
<th>Knowledge Base Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Literature Review &amp; Selection of Experts</td>
</tr>
<tr>
<td></td>
<td>Economic Impact of defects</td>
</tr>
<tr>
<td></td>
<td>Classification of defects</td>
</tr>
<tr>
<td></td>
<td>Structuring of knowledge</td>
</tr>
<tr>
<td></td>
<td>Establishing origins of defects</td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of defects</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>Analysis &amp; Software Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Develop and mail questionnaire</td>
</tr>
<tr>
<td></td>
<td>Analyze questionnaire responses</td>
</tr>
<tr>
<td></td>
<td>Implement in software</td>
</tr>
<tr>
<td></td>
<td>Industry-wide economic impact</td>
</tr>
<tr>
<td></td>
<td>Develop software manual</td>
</tr>
<tr>
<td></td>
<td>Debug/field-test software</td>
</tr>
<tr>
<td></td>
<td>Gather data for other garments</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>Refinement &amp; Knowledge Base Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete software development</td>
</tr>
<tr>
<td></td>
<td>Complete software manual</td>
</tr>
<tr>
<td></td>
<td>Develop training program</td>
</tr>
<tr>
<td></td>
<td>Complete extended defects knowledge base (other garments)</td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of methodology</td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software Product</td>
</tr>
</tbody>
</table>

**ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE**

**PERFORMANCE PERIOD:** 020189 - 022889
TECHNICAL REPORTS, MONTHLY
APPAREL MANUFACTURING TECHNOLOGY CENTER
SHORT TERM RESEARCH PROJECTS
DLA900-87-D-0018-0001
DLA900-87-D-0018-0002
DLA900-87-D-0018-0003
PERFORMANCE PERIOD: 881201 - 881231

Submitted By:
Susan Griffin

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

January 15, 1989

Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
DESIGN AND DEVELOPMENT OF A GENERIC ARCHITECTURE
PHASE I: FUNCTIONAL ARCHITECTURE

December Activities

The preliminary functional models of the major departments at Oxford Slacks were completed.

AMTC researchers presented the functional model of trouser manufacturing to Oxford management. The presentation was based on the manufacturing model for illustration purposes. Copies of all models developed were distributed to Oxford’s team for review and critique. Oxford’s feedback is expected in mid-January.

Sundaresan discussed the upcoming AAMA CIM/COM meeting with Mr. Joe Baran of Model Garment Company. This meeting is expected to be organizational rather than technical in nature. Sundaresan advised Mr. Baran that AMTC would like to share research results with the group and recruit additional participants for the project.

Sundaresan met with Don O’Brien and Dan Gearing to discuss project progress to date.

Index Technology’s Excelerator software has been installed.

Plans for January

Modify the functional model based on Oxford’s feedback.

Continue evaluation of other IDEF software tools.

Continue literature search for other manufacturing methodologies.

Investigate the feasibility of including other interested companies (e.g., Model Garment) in the project so the model could be reviewed and modified to ensure generality.
December Activities

Howard Olson met with Hubert Blessing, Director of Research and Development at Levi Strauss. The purpose of the meeting was to learn more about Levi’s approach to manufacturing and procuring jeans, and to obtain direction for AMTC’s work.

Levi places emphasis on automation of materials handling due to its significant return on investment. Quality, price and delivery of goods are assumed factors in the sewing facilities, so the Research and Development group concentrates on fine tuning plants and processes for maximum production. The attachment details other information obtained during the visit.

Work is continuing on the development of the machinery data base and the calculation of production costs.

Information from DPSC regarding quality problems in past procurement efforts was analyzed.

The industry questionnaire is being developed.

Plans for January

Continue interactions with DPSC and track new procurement of utility trousers.

Visit Haggar, Oxford Slacks, Farah, and two or three other commercial apparel manufacturers to study contracting practices.

Complete work on the preliminary version of the questionnaire. Test the questionnaire’s validity by mailing to a sample group of companies.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

December Activities

Researchers held a meeting with the Quality Control Manager of Oxford Slacks to discuss his possible involvement in the project.

A graduate research assistant was selected and has joined the project team.

DPSC provided defects analysis information to the AMTC team. A study of this data led to a preliminary estimate of the distribution of the types of defects in utility trousers.

A questionnaire is being developed to send to apparel manufacturers. This tool will assess the financial ramifications of defects as well as the different types of defects currently experienced in the apparel industry.

Review of literature in the area of fabric and apparel defects was begun.

Plans for January

Complete work on the initial version of the questionnaire and test its validity by mailing to a sample group of companies.

Continue literature review.

Identify companies for participation in the research effort.
TECHNICAL REPORTS, MONTHLY
APPAREL MANUFACTURING TECHNOLOGY CENTER
SHORT TERM RESEARCH PROJECTS
DLA900-87-D-0018-0001
DLA900-87-D-0018-0002
DLA900-87-D-0018-0003
PERFORMANCE PERIOD: 890101 - 890131
Submitted By:
Susan Griffin
Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology
February 15, 1989
Sponsored By:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Defense Logistics Agency position, policy, or documentation.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PHASE I: KNOWLEDGE BASE DEVELOPMENT

January Activities

Dr. Krishna Parachuru made a two-day visit to N.C. State and collected technical information on fabric and sewing defects in general, and defects in trouser manufacturing in particular. He discussed the project with Dr. Peyton Hudson and Dr. Trevor Little. Dr. Parachuru also made several visits to Oxford Slacks, spending time in the sewing and pressing departments to obtain an initial background on the range and extent of defects encountered in trouser manufacturing. He also analyzed in-house quality control procedures, obtained information on the classification of defects and allowable tolerances in the sewing department, and general guidelines issued to shop floor workers in the sewing and pressing departments.

A questionnaire for collecting information on trouser defects has been developed. GTRI researchers are modifying the final document which will be distributed to AMTC Steering Committee members during February.

Plans for February

Complete work on the final version of the questionnaire and test its validity by mailing to Steering Committee members.

Continue collection of literature related to garment defects and the establishment of knowledge-based expert systems.

Initiate classification and structuring of available information on garment defects.

Establish working contact with select group of apparel quality control experts.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

1. PROJECT REVIEW

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of October 1989. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan, graduate student working on his M.S. thesis in this area, is the Graduate Research Assistant on the project.

1.3 Travel

None specifically for this project (see 2.3 in SJ-TR-PROC-8910).
II. RESEARCH STATUS

The progress achieved on the specific tasks is reviewed in this section.

II.1 Development of First Prototype

Software implementation for the analysis of finished fabric defects has been completed. The developed prototype consists of three separate knowledge bases: one each for point defects, line defects and area defects. Preliminary work is also underway to design the user interface. The aim is to build a friendly and customized front-end for the defects analysis system. This will insulate the user from the inner workings of Nexpert, the software shell being used for the system.

II.2 Testing and Refinement

Testing of the prototype for coverage and consistency has been carried out. Based on the results, the prototype has been refined extensively. Work is underway to integrate the three separate knowledge bases into a single cohesive one.

II.3 Classification of Sewing Defects

The review of information on sewing defects continued during the month. Based on this review, work is in progress to define a general scheme of classification and hierarchical listing of sewing defects. This scheme will serve as the basis for software implementation.

II.4 Response Rate on Questionnaires

Despite the extensive mailing undertaken for the questionnaires, the response rate has been poor. Therefore, it is not possible to make any general conclusions (from the limited data) on the economic impact of defects in apparel manufacturing. Plans are being formulated for this purpose. Options being considered include telephone calls, mailings and visits to plants.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.
III. PLANS FOR NEXT MONTH

The specific plans for the coming month are outlined in this section.

III.1 Refinement of Prototype

Work on integrating the three separate knowledge bases in the prototype into a single knowledge base will be continued. The resulting system will be tested and debugged. Work on linking the system to a database for keeping track of cumulative defect statistics will be initiated. However, this work will commence only when Oracle is made available for the Sun 386i (expected to occur soon).

III.2 Sewing Defects Classification Scheme

Work on the sewing defects classification scheme will be continued. Once this scheme is developed, the software implementation will begin.

III.3 User Interface

Work on the initial version of the user interface will be continued.

III.4 Response Rate on Questionnaires

The plan for increasing the response to the questionnaires will be finalized and implementation will begin.

III.5 Travel

A visit to Coastal Industries will be planned.
Here is the plain text representation of the image:

### PHASE I
- **Knowledge Base Development**
  - Literature Review & Selection of Experts
  - Economic Impact of defects
  - Classification of defects
  - Structuring of knowledge
  - Establishing origins of defects
  - Identifying remedies of defects
  - Technical Report

### PHASE II
- **Analysis & Software Development**
  - Develop and mail questionnaire
  - Analyze questionnaire responses
  - Implement in software
  - Industry-wide economic impact
  - Develop software manual
  - Debug/field-test software
  - Gather data for other garments
  - Technical Report

### PHASE III
- **Refinement & Knowledge Base Extension**
  - Complete software development
  - Complete software manual
  - Develop training program
  - Complete extended defects
  - Knowledge base (other garments)
  - Analyze Choice of methodology
  - Final Report & Demonstrate Software Product

---

**ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING**

**PROGRAM SCHEDULE**

**PERFORMANCE PERIOD: 100189 - 103189**
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review For November

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of November 1989. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan, graduate student working on his M.S. thesis in this area, is the Graduate Research Assistant on the project.

1.3 Travel

No travel was conducted specifically for this project.
II. Research Status

The progress achieved on the specific tasks is reviewed in this section.

II.1 Development of First Prototype

The developed software prototype consists of three separate knowledge bases: one each for point defects, line defects and area defects. Work is in progress to integrate these three knowledge bases. A good amount of progress has been achieved on the design of the user interface, as well. The aim is to build a friendly and customized front-end for the defects analysis system. This will insulate the user from the inner workings of Nexpert, the software shell being used for the system.

II.2 Classification of Sewing Defects

The two applicable military specifications (MIL-STD-1488F and MIL-STD-87062A) are currently being incorporated into the generalized hierarchical network for sewing defects. Software implementation of sewing defects will commence after all the military specifications are satisfactorily represented in the defects network.

II.3 Response Rate on Questionnaires

Despite the extensive mailing undertaken for the questionnaires, the response rate has been poor. Therefore, it is not possible to make any general conclusions (from the limited data) on the economic impact of defects in apparel manufacturing. Plans have been formulated for improving the response rate; the questionnaires have been mailed out to trouser/apparel manufacturers. Other options being considered include telephone calls and visits to plants.
III. Plans For Next Month

The specific plans for the coming month are outlined in this section.

III.1 Refinement of Prototype

Work on integrating the three separate knowledge bases in the prototype into a single knowledge base will be completed. The complete system will then be ready for testing by selected experts from the industry. Work on linking the system to a database for keeping track of cumulative defect statistics will be initiated. However, this work will commence only when Oracle is made available for the Sun 386i (expected to occur soon).

III.2 Sewing Defects Classification Scheme

Work on the sewing defects classification scheme will be continued. Once this scheme is developed, the software implementation will begin.

III.3 User Interface

Work on the initial version of the user interface will be continued.

III.4 Response Rate on Questionnaires

The response to this round of mailings will be tracked; the received answers will be analyzed and added to the database.

III.5 Procurement of Sample Defects

Discussions are underway with fabric manufacturers to obtain samples covering the whole range of manufacturing defects.

III.6 Travel

A visit to Oxford Slacks is being planned. The visit will be utilized to seek clarifications on a few selected sewing defects.
<table>
<thead>
<tr>
<th>PHASE I</th>
<th>Knowledge Base Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Literature Review &amp;</td>
</tr>
<tr>
<td></td>
<td>Selection of Experts</td>
</tr>
<tr>
<td></td>
<td>Economic Impact of defects</td>
</tr>
<tr>
<td></td>
<td>Classification of defects</td>
</tr>
<tr>
<td></td>
<td>Structuring of knowledge</td>
</tr>
<tr>
<td></td>
<td>Establishing origins of defects</td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of defects</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>Analysis &amp; Software Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Develop and mail questionnaire</td>
</tr>
<tr>
<td></td>
<td>Analyze questionnaire responses</td>
</tr>
<tr>
<td></td>
<td>Implement in software</td>
</tr>
<tr>
<td></td>
<td>Industry-wide economic impact</td>
</tr>
<tr>
<td></td>
<td>Develop software manual</td>
</tr>
<tr>
<td></td>
<td>Debug/field-test software</td>
</tr>
<tr>
<td></td>
<td>Gather data for other garments</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>Refinement &amp; Knowledge Base Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete software development</td>
</tr>
<tr>
<td></td>
<td>Complete software manual</td>
</tr>
<tr>
<td></td>
<td>Develop training program</td>
</tr>
<tr>
<td></td>
<td>Complete extended defects</td>
</tr>
<tr>
<td></td>
<td>Extended defects knowledge base (other garments)</td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of methodology</td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software Product</td>
</tr>
</tbody>
</table>

ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERFORMANCE PERIOD 110189 - 113089
I. Project Review For December

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of November 1989. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan, graduate student working on his M.S. thesis in this area, is the Graduate Research Assistant on the project.

1.3 Travel

No travel was conducted specifically for this project.
II. Research Status

The progress achieved on the specific tasks is reviewed in this section.

II.1 Development/Integration of Fabric Defects Prototype

The developed software prototype for fabric defects still consists of three separate knowledge bases: one each for point, line and area defects. While progress has been made in integrating the three segments, some inconsistencies observed in the software module for area defects has slowed down the process of integration. The problems encountered have since been solved. New attempts will be made to achieve a cohesive integration of the area defects module into the three-module network.

II.2 Development of User Interface

The preliminary version of the user interface has been considerably modified with the intention of framing a revised high performance version. Work on the revised version is in progress and will continue through April/May.

II.3 Classification of Sewing Defects

The two applicable military specifications (MIL-STD-1488F and MIL-STD-87062A) have been incorporated into the generalized hierarchical network developed for sewing defects.

II.4 Validation of the Classification Scheme

Validation and refinement of the classification scheme for sewing defects has been initiated. The research team met with Professor Larry Haddock at Southern Tech and had an initial round of discussions on the proposed hierarchical network and the structuring of individual defects within the network. Further meetings with selected members of the Apparel Quality Committee (of the AAMA) are being scheduled in order to achieve a further refinement and finalization of the classification scheme for sewing defects.

II.5 Response Rate on Questionnaires

Despite the extensive mailing undertaken for the questionnaires, the response rate has been poor. Therefore, it is not possible to make any general conclusions (from the limited data) on the economic impact of defects in apparel manufacturing. The plan formulated for improving the response rate was implemented. Telephone calls were made to 107 companies, some repeatedly. Even then the response rate hasn’t been encouraging - - only a handful have responded. Efforts will, however, continue.
II.6 Acquisition of Oracle Database Program

The Oracle database program has been acquired and installed on the Sun 386i. The program will be used to acquire and project cumulative defect statistics.

III. Plans For Next Month

The specific plans for the coming month are outlined in this section.

III.1 Integration of Fabric Defects Prototype

The integration of the three separate knowledge base modules on fabric defects will be completed during January. Experts from Southern Tech are expected to test the integrated version during January-February.

III.2 Extended Review of the Defects Classification Scheme

Attempts will be made over the few months to interact with as many apparel experts as possible with the intention of refining and validating the classification scheme for sewing defects. Software development will not be halted during this validation phase -- the two activities will proceed simultaneously.

III.3 Response Rate on Questionnaires

The response to this round of mailings will be tracked; the received answers will be analyzed and added to the database.

III.4 Procurement of Sample Defects

Discussions are underway with fabric manufacturers to obtain samples covering the whole range of manufacturing defects.

III.5 Travel

Visits are planned to Levi Strauss and Co., Knoxville, Tennessee and Riverside Manufacturing Co., Moultrie, GA. The developed classification scheme for sewing defects will be discussed with these industry experts.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PROGRAM SCHEDULE

PERIOD ENDING 120189 - 123189
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for January

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of January 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan, graduate student working on his M.S. thesis in this area, is the Graduate Research Assistant on the project.

1.3 Travel

Dr. Krishna Parachuru and Dr. Phiroze Dastoor made two separate trips to Levi Strauss & Company and held discussions with experts responsible for fabric and sewing quality. On the first occasion, they met with Mr. Waverly Watkins (Director, Fabric Evaluation) and obtained his views on the design and development of a diagnosis system for analyzing fabric defects. On the second visit, they met with Mrs. Amelia Goodrow (Superintendent, Sewing Quality) and discussed the requirements for analyzing sewing defects. The two visits to Levi Strauss & Company enabled the researchers to obtain an overall view of the industry's requirements vis-a-vis the defects diagnosis system.

Dr. Phiroze Dastoor and Dr. Krishna Parachuru also made two trips to Southern College of Technology and discussed the same issues with Professor Larry Haddock, Mr. Dale Stewart and other experts at AMTC.
II. Research Status

The progress achieved on the specific tasks is reviewed in this section.

II.1 Development/Integration of Fabric Defects Prototype

The problems hindering integration of the three separate knowledge bases on fabric defects have been overcome. The integration has been successful and software testing is now complete. The Fabric Defects Analysis System (FDAS) is now being tested with the help of sample defects procured from the industry and volunteer test subjects. This allows verification of the system's diagnostic performance against actual manufacturing defects whose identity and causes are known prior to their screening on the system.

II.2 Development of User Interface

The preliminary version of the user interface has been considerably modified with the intention of framing a revised high performance version. Work on the revised version is in progress and will continue through April/May.

II.3 Validation of the Classification Scheme

The classification scheme which is still on paper is being carefully scrutinized by the first group of industry experts to whom the scheme has been supplied. The feedback from experts is expected within the next few weeks.

II.4 Response Rate on Questionnaires

Despite the extensive mailing undertaken for the questionnaires, the response rate has been poor. Therefore, it is not possible to make any general conclusions (from the limited data) on the economic impact of defects in apparel manufacturing. Additional efforts addressing this issue have yielded very little benefits.

II.5 Testing of Fabric Defects Prototype

Preliminary testing and validation of FDAS has been initiated. Denim fabric samples with various defects are being used for this purpose. To simulate the system's use on the shopfloor, individuals not familiar with the system implementation details are being used as subjects. Though FDAS' response has been encouraging, the testing process is yielding some valuable information that will be used for refining the system. The series of screen shots for a typical interaction is shown in Figure 1.
II.6 Draft of M.S. Thesis

Mr. K. Srinivasan is making further revisions to his M.S. thesis draft based on input from his thesis advisor, Dr. Jayaraman.

II.7 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. Plans for Next Month

The specific plans for the coming month are outlined in this section.

III.1 Testing of Fabric Defects Prototype

Testing of the integrated system by experts from Southern College of Technology will be accomplished within the next few weeks. After this, at least three experts from the industry will be asked to evaluate the system and give their feedback on the accuracy and user friendliness of the system.

III.2 Extended Review of the Defects Classification Scheme

Attempts will be made over the next few months to interact with as many apparel experts as possible with the intention of refining and validating the classification scheme for sewing defects. Software development will not be halted during this validation phase -- the two activities will proceed simultaneously.

III.3 Procurement of Sample Defects

The management of Cone Mills has agreed to supply denim samples containing the whole range of manufacturing defects. The sample defects which are expected to arrive by the third week of February will be of enormous help in testing and validating the Fabric Defects Analysis System (FDAS).

III.4 Implementation of Sewing Defects

Software Implementation of sewing defects will be initiated in February. The recommendations/suggestions already put forth by the expert reviewers will be incorporated in the first implementation. Suggestions received during the implementations phase will also be utilized.
III.5 Produce Final Draft of M.S. Thesis

Mr. Srinivasan will produce the final draft of his M.S. thesis for submission to the Thesis Reading Committee.

III.6 Travel

Additional visits are being scheduled to Levi Strauss & Company, Riverside Manufacturing Company, Greenwood Mills, and Southern College of Technology. These visits will be utilized to discuss the merits and demerits of a group of alternative system design ideas the research team has considered at some length. The meetings will also focus on the rationalization of the classification scheme developed for sewing defects.

III.7 Prepare for Philadelphia Conference

Time will be spent on preparing for the upcoming conference of apparel researchers from various centers being organized by DLA at the Philadelphia College of Textiles and Science, February 14-16, 1990.
(a). User selects Point Defect

(b). User identifies orientation of defect
Select the best description of the repeat pattern of the point defect, along the length of the fabric.

- Random
- Continuous
- Isolated
- Random
- Regularly Repeating

(c). User selects pattern of defect along fabric length

Select the best description of the repeat pattern along the width of the fabric.

- Isolated
- Random
- Regularly Repeating

(d). User selects pattern of defect along fabric width
Is there a thick place with the size of the head of a pin in the yarn?

(e). User describes size of defect
Probable Causes:

Low fiber maturity co-efficient.
Too many beating points in the opening room.
Insufficient extraction of waste in carding and combing.

Suggested Remedy:

The fiber maturity co-efficient should be at least 75%.
Try fewer beating points and avoid heavy beaters such as three bladed beaters for fine fibers. Even for coarse and trashy cottons, fewer than four beating points should be used.
Try higher extraction of flat strips and comber noils.

(e) FDAS response: defect causes and remedies

FIGURE 1: USER INTERACTION WITH FDAS
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PROGRAM SCHEDULE

Performance Period 1-1-90 to 1-31-90
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

1. Project Review for February

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November, 1988 and is being carried out in three phases. This report reviews the progress made during the month of February 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan, graduate student working on his M.S. thesis in this area, is the Graduate Research Assistant on the project.

1.3 Travel

Dr. Krishna Parachuru and Dr. Phiroze Dastoor visited Graniteville Mills located in Graniteville, S.C. They met with Mr. A. G. Blackmon a leading fabric quality expert in the U.S. The discussions centered on the classification scheme suggested by him in his book, "Manual of Standard Fabric Defects" and also on the criticality of various fabric defects. The discussions also helped the research team to know more about defects that are specific to denim goods and also about defects that predominate when open-end spun yarns are used in place of ring spun yarns. Mr. Blackmon pointed out that depending on the technology used for yarn and fabric production, a small group of about 10-15 defects occur on a high frequency basis and contribute to roughly 60% of total defects found in the finished fabric. Mr. Blackmon also suggested that any knowledge-based system meant for analyzing defects in apparel fabrics should have a segregated knowledge block to identify and diagnose defects that are common to a particular manufacturing situation. This way, it would be possible to cut down the time required for the identification and diagnosis of defects characterized by high frequency of occurrence.
Dr. Phiroze Dastoor and Dr. Krishna Parachuru also visited Southern Tech and Levi Strauss Company, during the period under review. On their trip to Levi Strauss & Company, they met with the Sewing Quality Superintendent, Mrs. Amelia Goodrow and discussed the modifications needed to the system specifications sent earlier.

At Southern Tech, the research team met with Professor Larry Haddock, Mr. Dale Stewart and other members of AMTC. The discussions at Southern Tech again centered on the advantages and disadvantages associated with the system configuration proposed by the research team.

Dr. Jayaraman attended the DLA-sponsored Academic Apparel Research Conference held in Philadelphia, PA, during February 14-16, 1990. He made a presentation on the apparel defects research endeavor.
II. Research Status

II.1 Testing of Fabric Defects Prototype

Testing and evaluation of the Fabric Defects Analysis System (FDAS) began soon after the three knowledge bases were integrated into one. Sample defects procured from a major manufacturer of denim fabrics have been used to assess the diagnostic performance of the system against actual manufacturing defects whose identity and causes are known beforehand. To simulate the system's use on the shop floor, individuals not familiar with the system implementation details were chosen as test subjects. Results of diagnostic performance proved encouraging and highlighted the need for a few refinements, some changes in defect descriptions and a few additions to the system to take care of all the commonly used manufacturing technologies for yarn and fabric manufacture.

II.2 Development of User Interface

The first version of the modified user interface to the Fabric Defects Analysis Systems (FDAS) has been completed. This version will be upgraded to the next improved version based on suggestions put forth by the users within the next 4-5 weeks. Only those modifications that are likely to aid in improving speed, simplicity and functionality of the system will be considered for implementation.

II.3 Validation of the Classification Scheme

The classification scheme which is on paper is still being evaluated by industry experts to whom the scheme has been supplied. The feedback from several experts is expected by the end of this month.

II.4 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.
III. Plans for Next Month

III.1 Testing of Fabric Defects Prototype

Locally available test subjects are currently being used to test the efficacy of the system. Once this phase of testing is completed, experts from Southern Tech and from nearby apparel plants will be requested to test the system and give their feedback.

III.2 Extended Review of the Defects Classification Scheme

Attempts are being made to interact with as many apparel experts as possible with the intention of refining and validating the classification scheme for sewing defects. Software development will not be halted during this validation phase -- the two activities will proceed simultaneously.

III.3 Procurement of Sample Defects

Cut samples of denim fabric containing different manufacturing defects have been received recently from Cone Mills. The samples received represent wide range of fabric weights, manufacturing technologies, process parameters and raw materials. It is believed that these samples will serve as excellent tools to further check and improve the efficacy of FDAS.

III.4 Implementation of Sewing Defects

Software implementation of sewing defects scheduled to begin in February has been postponed due to non-finalization of the system configuration. Implementation will commence as soon as the system configuration is finalized in consultation with industry experts who have already been asked to provide input into the system design.

III.5 M.S. Thesis Defense

Mr. Srinivasan will defend his M.S. thesis entitled FDAS: A Knowledge-Based Framework For Analysis of Defects in Woven Textile Structures. A copy of his thesis will then be available for reference.

III.6 Travel

Additional visits are being scheduled to Levi Strauss & Company, Riverside Manufacturing Company, Swift Textiles, and Southern College of Technology. These visits will be utilized to gain input for system design and also to rationalize the classification scheme developed for sewing defects.
<table>
<thead>
<tr>
<th>PHASE I</th>
<th>Knowledge Base Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Literature Review &amp;</td>
</tr>
<tr>
<td></td>
<td>Selection of Experts</td>
</tr>
<tr>
<td></td>
<td>Economic Impact of defects</td>
</tr>
<tr>
<td></td>
<td>Classification of defects</td>
</tr>
<tr>
<td></td>
<td>Structuring of knowledge</td>
</tr>
<tr>
<td></td>
<td>Establishing origins of defects</td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of defects</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>Analysis &amp; Software Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Develop and mail questionnaire</td>
</tr>
<tr>
<td></td>
<td>Analyze questionnaire responses</td>
</tr>
<tr>
<td></td>
<td>Implement in software</td>
</tr>
<tr>
<td></td>
<td>Industry-wide economic impact</td>
</tr>
<tr>
<td></td>
<td>Develop software manual</td>
</tr>
<tr>
<td></td>
<td>Debug/field-test software</td>
</tr>
<tr>
<td></td>
<td>Gather data for other garments</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>Refinement &amp; Knowledge Base Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete software development</td>
</tr>
<tr>
<td></td>
<td>Complete software manual</td>
</tr>
<tr>
<td></td>
<td>Develop training program</td>
</tr>
<tr>
<td></td>
<td>Complete extended defects</td>
</tr>
<tr>
<td></td>
<td>knowledge base (other garments)</td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of methodology</td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software</td>
</tr>
<tr>
<td></td>
<td>Product</td>
</tr>
</tbody>
</table>

**ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING**

**PROGRAM SCHEDULE**

PERFORMANCE PERIOD 020190 - 022890
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for March

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in November, 1988 and is being carried out in three phases. This report reviews the progress made during the month of March 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

I.3 Travel

The research team visited Swift Textiles in Columbus, GA, to obtain first hand knowledge of the defects associated with indigo dyeing of denim warp. The research team had a close look at the type of equipment used for the application of indigo and vat colors on the warp yarn. Discussions were also held with the technical staff of the dyeing department to better understand the reasons for the occurrence of shade-related defects in denim fabrics. Discussions revealed that proper dyeing procedures and regular maintenance of dyeing equipment were important for minimizing shade-related defects in denim fabrics.

The visit to Swift Textiles has also been utilized to obtain information on the frequency of occurrence of different weaving and finishing defects. The information obtained confirms the earlier observation of Mr. A. G. Blockman that a small group of 10-12 repeatedly occurring mill flaws contribute to roughly 60% of the total finished fabric defects. The defect composition of this small group and the frequency of occurrence of individual defects within the group have been found to depend not only on yarn and fabric manufacturing technologies used but also on fabric construction parameters such as weight/yd², fiber composition of warp and filling yarns, finishing treatments employed, etc.
The research team also spent considerable time at Southern College of Technology, in discussions with Dale Stewart and Jim Young. The discussions focused on the diagnosis of sewing/garment assembly defects. Factors responsible for the occurrence of "Raw Edges" have been discussed at length and listed in the proper sequential order for incorporation into software.

II. Research Status

II.1 Testing of Fabric Defects Prototype

In-house evaluation of the Fabric Defects Analysis System (FDAS) has been completed. Members of the research team as well as other test subjects who did not have prior knowledge of the system were involved in the evaluation. The diagnostic performance of the system was checked using large numbers of sample defects obtained from two different industries. Some significant gaps in the diagnostic performance of the system were observed. These gaps mainly relate to variations in manufacturing technology. The gaps are now being bridged and the knowledge base is being expanded to include the manufacturing variations prevalent in the industry.

II.2 Development of User Interface

The User interface has been further upgraded, based on the working experience gained and the suggestions put forth by the test subjects. The interface will eventually be capable of running multiple diagnosis sessions on several computers, all connected to a single defects database.

II.3 Validation of the Classification Scheme

The Classification Scheme for sewing/manufacturing defects is now reasonably well scrutinized by industry experts. Opinions received within the next 2-3 months will also be considered for implementation.

II.4 Database Structuring

Interfacing of the Oracle database with Nexpert is in progress. The fabric defects Analysis System (FDAS) will use the database not only to keep defect statistics but also to generate quality reports and to alert the manufacturer whenever the actual occurrence of defects exceeds predetermined levels.

II.5 M.S. Thesis

Mr. K. Srinivasan has successfully defended his M.S. Thesis entitled "FDAS: A Knowledge-Based Framework For Analysis of Defects in Woven Structures."
III. Plans for Next Month

III.1 Testing of Fabric Defects Prototype

Experts from Southern Tech and Graniteville Mills will be invited to test the Fabric Defects Analysis System during April and May.

III.2 Extended Review of The Defects Classification Scheme

Comments on the Classification Scheme for sewing defects are expected from a few more industry experts to whom copies of the Scheme were mailed earlier. The opinion expressed by these experts will also be weighed and suggested changes will be incorporated as appropriate.

III.3 Expansion of Fabric Defects Knowledge-Base

Based on the gaps detected in the diagnostic performance, FDAS will be expanded to include diagnostic details for some special defects associated with rotor spinning, air-jet weaving, indigo dyeing etc. Visits to local industries and discussions with experts yielded considerable information on the occurrence and prevention of these technology related defects. The information will be incorporated into the system to improve its diagnostic performance.

III.4 Reorganization of FDAS

Work will be initiated to reorganize FDAS such that the diagnostic information for the small group of frequently occurring defects can be accessed and referred to with minimum expense of time. The System will be reorganized such that all the information on the small group of defects is present at the front end.

III.6 Travel

Visits have been scheduled to Coastal Industries and to Southern College of Technology. The two-day visit to Coastal Industries will be mainly utilized to observe the occurrence of sewing defects on the shop-floor and to learn more about the causes and possible remedies of frequently occurring sewing faults. Discussions at Southern Tech will also focus on the diagnosis of sewing defects.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

Period Ending 03-31-90
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

1. Project Review for April

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price, but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort fund by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November, 1988 and is being carried out in three phases. This reviews the progress made during the month of April 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant.

1.3 Travel

The research team made a 2-day visit to Coastal Industries in Selma, AL to obtain first-hand knowledge of defects occurring in cutting and assembly operations. The nature and type of defects that could arise at each individual assembly operation has been identified and the probable causes of these defects have also been analyzed at length. A better understanding of some of the sewing faults has been obtained. Information on the frequency of occurrence of individual defects and the steps taken to control them have also been gathered. The visit to Coastal was concluded with a 2-hour discussions with the plant manager and quality control manager.

The research team also spent considerable time at Southern Tech discussing the possible causes of specific sewing/assembly defects in denim trousers. Factors responsible for the occurrence of "Open Seams" have been discussed at length and listed in the proper sequence for incorporation into software.
II. Research Status

II.1 Testing of Fabric Defects Prototype

The diagnostic performance of the fabric defects prototype (FDAS) continues to be verified using large numbers of sample defects obtained from different industries. Some significant gaps in the diagnostic performance of the system were observed. These gaps mainly relate to variations in manufacturing technology. The gaps are now being bridged and the knowledge base is being expanded to include the manufacturing variations prevalent in the industry.

II.2 Development of User Interface

The user interface has been further upgraded based on the working experience gained and the suggestions put forth by the test subject. The interface is being further developed to work with a relational data base which will keep track of cumulative defects statistics.

II.3 Validation of the Classification Scheme

The classification scheme for sewing/manufacturing defects is being modified on the basis of input from industry. The scheme is now close to final shape and is ready for implementation in software. However, opinions received in the next 2-3 months will also be considered for implementation.

II.4 Database Structuring

Interfacing of the Oracle database with Nexpert is in progress. The fabric defects analysis system (FDAS) will use the database not only to keep defect statistics but also to generate quality reports and to alert the manufacturer whenever the actual occurrence of defects exceeds predetermined levels.
III. Plans for Next Month

III.1 Testing of Fabric Defects Prototype

Evaluation of FDAS by industry experts scheduled to begin in April was delayed to add information on technology related defects to the knowledge base and to complete the integration of the data base system with the knowledge base.

III.2 Expansion of Fabric Defects Knowledge-Base

Based on the gaps detected in the diagnostic performance, FDAS will be expanded to include diagnostic details for some special defects associated with rotor spinning, air-jet weaving, indigo dyeing, etc. Visits to local industries and discussions with experts yielded considerable information on the occurrence and prevention of these technology related defects. This information is being incorporated into the system to improve its diagnostic performance.

III.3 Reorganization of FDAS

FDAS is being reorganized such that the diagnostic information for the small group of frequently occurring defects can be accessed and referred to with minimum expense of time. This will be an additional feature which comes on top of the existing system.

III.4 Travel

Visits have been scheduled to Riverside Manufacturing and to Southern College of Technology. The visit to Riverside will allow researchers to observe the occurrence of sewing defects on the shop-floor and to learn more about the causes and possible remedies of frequently occurring sewing faults. Issues related to the influence of levels of manufacturing technology on defects will also be discussed. Work with Southern Technology will continue to focus on the diagnosis of sewing defects.
# Analysis of Defects in Trouser Manufacturing Program Schedule

**Period Ending 04-30-90**

## Phase I
Knowledge Base Development
- Literature Review & Selection of Experts
- Economic Impact of defects
- Classification of defects
- Structuring of knowledge
- Establishing origins of defects
- Identifying remedies of defects
- Technical Report

## Phase II
Analysis & Software Development
- Develop and mail questionnaire
- Analyze questionnaire responses
- Implement in software
- Industry-wide economic impact
- Develop software manual
- Debug/field-test software
- Gather data for other garments
- Technical Report

## Phase III
Refinement & Knowledge Base Extension
- Complete software development
- Complete software manual
- Develop training program
- Complete extended defects
  - Knowledge base (other garments)
- Analyze Choice of methodology
- Final Report & Demonstrate Software Product

---

**Program Schedule**

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Task |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

---

**ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING**

---
I. Project Review for May

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in November, 1988 and is being carried out in three phases. This report reviews the progress made during the month of May 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant.

I.3 Travel

Drs. Parachuru and Dastoor made two separate visits to Southern College of Technology and discussed the technological variations present in the U.S. apparel industry and their influence on sewing/assembly defects. Mr. Bill Cameron and Mr. Howard Pettigrew contributed to the discussions. Discussions revealed, information about the type of manufacturing defects associated with below average, average and above average technology levels. Suggestions were also received for further simplification of the classification scheme for sewing/assembly defects.

The expected visit to Riverside Manufacturing Company did not materialize due to the last minute cancellation of the same by the technical experts who were supposed to meet with the research team.
II. Research Status

II.1 Testing of Fabric Defects Prototype

The diagnostic performance of the Fabric Defects Prototype (FDAS) has been considerably improved to account for gaps identified during the testing phase. Progress is still being made in terms of including defects that are characteristic of the latest yarn and fabric manufacturing technologies.

II.2 Development of User Interface

The high level design of a graphical user interface for communicating with the defects database as well as FDAS (written in Nexpert) has been completed. However, its implementation in software has run into some unforeseen problems which are currently being addressed (please see Section II.5)

II.3 Validation of the Classification Scheme

The garment defects classification scheme (excluding packing and trim defects) has achieved final status. Final modifications of the classification scheme were made recently on the basis of input received from Mr. Bill Cameron of Southern Tech.

II.4 Software Implementation of Sewing Defects

Software implementation of the defects classification scheme (latest version) has been initiated. The first phase of implementation will continue through July.

II.5 Database Structuring

The final integration of Oracle database with Nexpert and the user interface has been delayed due to unexpected problems observed in Nexpert itself. The Georgia Tech research team is currently working with the developer of Nexpert to overcome the problems faced in the integration.

II.6 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.
III. Plans for Next Month

III.1 Testing of FDAS

Mr. A. G. Blackmon of Graniteville Mills, a recognized expert on fabric defects, has been approached for the evaluation of FDAS. A date will be scheduled shortly for his visit to Georgia Tech. Mr. Bill Cameron of Southern Tech has also agreed to test the diagnostic performance of FDAS. Both experts are expected to provide their feedback on the FDAS in the next few weeks.

III.2 Expansion of FDAS

The FDAS in its current shape is fully satisfactory in terms of coverage of the whole range of manufacturing defects associated with denim fabrics. Of more importance from this point on, will be the need to adopt FDAS for working on a decentralized basis. This is necessary to make the system usable in the actual manufacturing environment. Planning and design of this type of distributed software model will begin soon.

III.3 Travel

Weekly visits to Southern College of Technology are being planned to continue discussions on sewing problems and to reexamine the defect classifications scheme in the light of issues surfacing during software implementation. Visits are also being planned to Russell Corporation and Wrangler division of V. F. Corporation. These visits will be used to understand more about the role of manufacturing technology on defect generation and the type of defects associated with different levels of technology.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERIOD ENDING 5/31/90
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for June

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of June 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan, graduate student working on his M.S. thesis in this area, is the Graduate Research Assistant on the project.

I.3 Travel

Research Investigators, Dr. Dastoor and Dr. Parachuru made two separate visits to the Southern College of Technology. On their first visit, they met with Mr. Bill Cameron and Mr. Howard Pettigrew and continued discussions on the possible causes of sewing/assembly defects and their dependence on manufacturing technology and worker training. On the second visit, several hours were spent on the shop-floor of the sewing facility in understanding the probable influence of machinery settings, speeds and handling variations on defect generation. Three different assembly operations (automatic belt loop tacking, J-stitching and pocket-setting) were analyzed at length to identify the possible problems that could arise as a result of improper settings & speeds and incorrect handling of in-process materials.

No outside factory visit was undertaken during the month because of problems faced in scheduling mutually convenient dates.
II. Research Status

II.1 Testing of Fabric Defects Prototype

All internal evaluation and upgradation of the Fabric Defects Prototype is now complete. One of the two external experts identified earlier is scheduled to test the system before the end of July. The expert has been requested to run the system as an outsider and give his opinion on the coverage, diagnostic accuracy and user friendliness of the system.

II.2 Development of User Interface

The implementation of the high-level user interface is yet to be completed. The problems mentioned last month were given attention during the second half of June and some of the difficulties have already been sorted out. However, the task of implementing the interface in a satisfactory manner is still pending.

II.3 Validation of the Classification Scheme

The garment defects classification scheme (excludes packing and trim defects) has achieved final status. Final modifications of the classification scheme were made recently on the basis of the input received from Mr. Bill Cameron of Southern Tech.

II.4 Software Implementation of Sewing Defects

This task is currently receiving a major portion of the research team’s time and attention. The first prototype of the Sewing Defects Analysis System [SDAS] will be ready within the next few weeks.

II.5 Database Structuring

The final integration of the Oracle database with Nexpert and the user interface has been delayed due to unexpected problems observed in the Nexpert product itself. The Georgia Tech research team is currently working with the manufacturer of Nexpert to overcome the problems faced in the integration.

II.6 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.
III. Plans for next month

III.1 Testing of FDAS

Mr. A. G. Blackman of Graniteville Mills Company, Graniteville, SC has agreed to test the FDAS during the middle of September. The above date has been suggested by Mr. Blackman himself to suit his schedule. Mr. Bill Cameron of Southern Tech is scheduled to test the system and give his feedback on July 12. Suggestions for improvement, if any, will be implemented after both the experts go through the evaluation process.

III.2 Expansion of FDAS

Work towards decentralizing the operation of FDAS has already begun. A theoretical design for the decentralized operation of FDAS will be ready by the end of this month while the software model can be expected to take shape by the end of August.

III.3 Travel

Visits to Southern College of Technology will continue after a short recess in the month of July. Visits to nearby apparel companies will be undertaken as and when need arises for technical discussions, clarifications and approval. Attempts are also being made to schedule visits to an apparel plant that works with different levels of manufacturing technology under one roof.
PHASE I
Knowledge Base Development
  Literature Review &
   Selection of Experts
   Economic impact of defects
   Classification of defects
   Structuring of knowledge
   Establishing origins of defects
   Identifying remedies of defects
   Technical Report

PHASE II
Analysis & Software Development
  Develop and mail questionnaire
  Analyze questionnaire responses
  Implement in software
  Industry-wide economic impact
  Develop software manual
  Debug/field-test software
  Gather data for other garments
  Technical Report

PHASE III
Refinement & Knowledge Base Extension
  Complete software development
  Complete software manual
  Develop training program
  Complete extended defects
  Knowledge base (other garments)
  Analyze choice of methodology
  Final report & demonstrate software product

ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING
PROGRAM SCHEDULE

PERIOD ENDING 6/31/90
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for July

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of July 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Mr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

I.3 Travel

No outside factory visit was undertaken by the research team during the month of July.

Dr. Jayaraman attended the International Clothing Conference on Objective Measurement of Fabric Properties and Automation in Apparel Manufacturing, held at the University of Bradford, UK, during July 9-11, 1990. Fabric handle plays a critical role in the garment manufacturing process (more so in the context of automated manufacturing); consequently, the objective measurement of fabric handle (e.g., using the Kawabata Hand Evaluation System) is a topic of extensive research in textile/apparel laboratories around the world. The Conference provided the opportunity to interact with fellow researchers from around the world and to learn about the various research endeavors.

Dr. Jayaraman also presented a paper entitled Relationship between KES Properties and Sewing Performance of Difficult-to-sew Woven Fabrics that was co-authored with Krishna Parachuru. This work was carried out in the Georgia Tech Kawabata Laboratory in cooperation with some textile/apparel companies.
Dr. Jayaraman proposed the setting up of an electronic journal (through internet and/or other networks) for the rapid exchange of information among researchers in various countries working in the textile/apparel field.

**In-process Sewing Defects:** Among the several papers at the three-day conference, the one on detecting defects as they occur on the sewing machine closely parallels the research effort currently headed by Dr. Howard Olson at AMTC.
II. Research Status

II.1 Testing of Fabric Defects Prototype

Mr. Bill Cameron of Southern Tech visited Georgia Tech campus on July 12 to evaluate the FDAS. He was orally briefed about the design and working of the system and was then taken through the system in a systematic way. He has been requested to contribute his apparel knowledge and expertise gained over a 30-year period toward further. He expressed satisfaction with the functioning of FDAS and shared some of his ideas on the design and development of a software system for the analysis of sewing defects.

II.2 Development of User Interface

The implementation of the high-level user interface for the FDAS Fabric Defects Analyses System is being given final touches before Mr. A. G. Blockman of Graniteville Mills arrives to test the system during the middle of September. Another user interface program is also being developed for the first prototype of the Sewing Defects Analysis System (SDAS).

II.3 Software Implementation of Sewing Defects

This task continues to be the main focus of the research team at the present time. All the possible sewing and assembly defects were incorporated into the defect classification network that was finalized earlier. Work is now in progress towards identifying and tabulating the whole range of causes and remedies for each individual defect. This information will then be implemented in the software and the first version of the Sewing Defects Analysis System is expected to be ready by the end of August.

II.4 Database Structuring

The manufacturers of Nexpert Software appear to have solved the earlier problems encountered in integrating Nexpert with the Oracle database. The research team will now renew efforts to satisfactorily integrate the FDAS with Nexpert and the Oracle database.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. Plans for Next Month

III.1 Testing of FDAS
In addition to Mr. A. G. Blockman, a number of other Quality Control experts from the textile and apparel industries are expected to visit the Bobbin Show in Atlanta. Several of these experts will be invited to Georgia Tech to evaluate the FDAS and to comment on the first version of the Sewing Defects Analysis System (SDAS).

III.2 Expansion of FDAS

Work towards decentralizing the operation of FDAS has already begun. The decentralized software model can be expected to take shape by the end of August.

III.3 Travel

At least two visits to Southern College of Technology are scheduled for the month of August. Visits to nearby apparel companies will be undertaken as and when need arises for technical discussions, clarifications and approval. Attempts are also being made to schedule visits to an apparel plant that works with different levels of manufacturing technology under one roof.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURE

I. Project Review for August

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of August 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

I.3 Travel

The research team did not visit any outside apparel company during the month of August.

Three separate trips were made by Dr. Dastoor and Dr. Krishna to Southern College of Technology. On these trips, they met with Mr. Bill Cameron and Mr. Howard Pettigrew and continued discussions on the factors influencing the quality of sewn products. Discussions centered mainly on the occurrence of skipped stitches, raw edges, open seams, broken stitches, needle chews and pleated seams. The origin of these defects has been discussed for each of the stitch/seam combinations outlines in the military specifications MIL-T-87062A.)
II. Research Status

II.1 Fabric Defects Prototype

A few final modifications to upgrade the FDAS (Fabric Defects Analysis System) from a "prototype" to a "system" version are currently being undertaken. Most of these modifications are in the form of minor changes to the system to enhance error handling and user help facilities. FDAS runs on both UNIX and DOS, with separate user interfaces.

II.2 Development of User Interface

The implementation of the high-level user interface for FDAS is receiving finishing touches. The user interface for the Sewing Defects Analysis System (SDAS) is under development.

II.3 Software Implementation of Sewing Defects

This continues to be the main task on hand. Information finalized through discussions with apparel experts at Southern Tech is being implemented into software. Discussion and implementation will go on simultaneously until the whole range of sewing defects and their causes and remedies are incorporated into software. Roughly one-third of the implementation has been completed now.

II.4 Database Structuring

The developers of Nexpert software have run into further problems with their database interface. This, in turn, has seriously affected the schedule of the research team. Efforts are being made to integrate the Oracle database with FDAS, using Nexpert.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. Plans for Next Month

III.1 Testing of FDAS

In addition to Mr. A. G. Blockman, a number of other Quality Control experts from the textile and apparel industries are expected to visit the Bobbin Show in Atlanta. Several of these experts will be invited to Georgia Tech to evaluate the FDAS and to comment on the first version of the Sewing Defects Analysis System (SDAS).
III.2 Expansion of SDAS

Work will continue on the design and implementation of the Sewing Defects Analysis System. The system will also be continuously tested and refined as it takes its final shape.

III.3 Travel

Visits on a weekly basis to Southern Tech have been scheduled. The entire research team will be spending several hours at the Bobbin show, interacting with technical experts, machinery manufacturers and executives from the apparel industry. A broad perspective of some of the problems faced by the research team during the implementation phase will be sought. Time permitting, the main features of the software system will also be discussed.
## ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

### PROGRAM SCHEDULE

<table>
<thead>
<tr>
<th>Period Ended: 8-31-90</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE I</strong></td>
</tr>
<tr>
<td>Knowledge Base Development</td>
</tr>
<tr>
<td>Literature Review &amp;</td>
</tr>
<tr>
<td>Selection of Experts</td>
</tr>
<tr>
<td>Economic Impact of defects</td>
</tr>
<tr>
<td>Classification of defects</td>
</tr>
<tr>
<td>Structuring of knowledge</td>
</tr>
<tr>
<td>Establishing origins of defects</td>
</tr>
<tr>
<td>Identifying remedies of defects</td>
</tr>
<tr>
<td>Technical Report</td>
</tr>
</tbody>
</table>

| **PHASE II** |
| Analysis & Software Development |
| Develop and mail questionnaire |
| Analyze questionnaire responses |
| Implement in software |
| Industry-wide economic impact |
| Develop software manual |
| Debug/field-test software |
| Gather data for other garments |
| Technical Report |

| **PHASE III** |
| Refinement & Knowledge Base Extension |
| Complete software development |
| Complete software manual |
| Develop training program |
| Complete extended defects knowledge base (other garments) |
| Analyze Choice of methodology |
| Final Report & Demonstrate Software Product |

### Diagram
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for September

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price, but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of September 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

1.3 Travel

The research team did not visit any apparel plants during the month of September.

Team members made four separate visits to Southern College of Technology. The visits were intended to continue discussions on sewing problems and the ways of tackling them. Discussions proceeded as per a modified approach. Each of the assembly operations listed in MIL-T-87062A was considered individually and the possibility of manufacturing defects occurring at each stage has been discussed. The factors responsible for defects at each stage have also been discussed at length. The first ten assembly operations listed in MIL-T-87602A have been covered so far.

The research team spent two full days at the Bobbin Show. Technical discussions on sewing problems were held with a number of experienced personnel, including the staff of TC2, Durkoff and Juki. The three main features of the show that attracted the attention of the research team were the full-felled seamer exhibited by TC2, the automatic patch pocket setter exhibited by Durkoff and the advanced sewing machine exhibited by Juki which automatically varies the sewing process parameters (speed, pressure, thread tension, etc.) based on the low stress mechanical properties of the fabric being sewn. The impact of a few of these developments on the occurrence of manufacturing defects is being considered at length.

Dr. Jayaraman attended the presentation by representatives of Japan's Technology Research Association of Automated Sewing Systems (TRAASS) on the various projects sponsored by MITI.
of Japan on automating garment manufacturing. The meeting was organized by TC2 in Raleigh, North Carolina. The presentations ranged from the development of software for process planning to the use of robot arms for sewing.

II. Research Status

II.1 Fabric Defects Analysis System (FDAS)

The software module of the FDAS (Fabric Defects Analysis System) has finally been upgraded from the prototype status. It runs on UNIX as well as MS-DOS.

II.2 Development of User Interface

The implementation of the final high-level user interface for FDAS is complete. A minor problem pertaining to suppression of a couple of error messages (UNIX Version) needs to be resolved. This problem, however, can be solved at the appropriate stage without much expense of time. The user interface for the Sewing Defects Analysis System (SDAS) is still under development.

II.3 Software Implementation of Sewing Defects

The task of software generation for the analysis of sewing defects continues to be the main focus of the research team. About 50% of software development has been completed so far. Information gathered from several different sources (apparel experts, text books, technical journals and research papers) is being further discussed and finalized before converting the same into software. Weekly discussions with Southern Tech colleagues are useful in this regard.

II.4 Database Structuring

The developers of Nexpert software have run into further problems with their database interface. This, in turn, has seriously affected the schedule of the research team. Efforts are being made to integrate the Oracle database with FDAS, using Nexpert.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. Plans for Next Month

III.1 Testing of SDAS

Work will continue on the design and implementation of the Sewing Defects Analysis System. The system will also be continuously tested and refined as it takes its final shape.
III.2  Database Interfaces

The interfacing of database software with FDAS and SDAS has been slowed down due to unexpected software problems. Since the long-term tracking of defect occurrences has always been an important system design goal, our effort at accomplishing this bridge will continue.

III.3  Travel

Regular visits to Southern College of Technology are scheduled on a weekly basis. Mr. Bill Cameron and Mr. Howard Pettigrew are expected to contribute their knowledge and experience to enrich and amplify the knowledge base gathered by the research team.
<table>
<thead>
<tr>
<th>Month</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I</td>
<td>Knowledge Base Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Literature Review &amp;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selection of Experts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Economic Impact of defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Classification of defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structuring of knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Establishing origins of defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE II</td>
<td>Analysis &amp; Software Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop and mail questionnaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze questionnaire responses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Implement in software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industry-wide economic impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop software manual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debug/field-test software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gather data for other garments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE III</td>
<td>Refinement &amp; Knowledge Base Extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete software development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete software manual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop training program</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete extended defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge base (other garments)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of methodology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERIOD ENDING 9-30-90
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for October

The production of high quality and defect-free goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of October 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on this project.

1.3 Travel

This month's travel activity did not include any outside factory visit.

There were frequent interactions between members of the research team and the AMTC apparel experts at Southern Tech. In addition to routine discussions on the phone, the teams met on four occasions during the month. Each scheduled meeting lasted for 2 1/2 hours. The discussions during the meetings focused on the factors responsible for Quality and Production Problems in cutting and sewing operations.
II. Research Status

II.1 Fabric Defects Analysis System

The software for the fabric defects system (DOS version) is now being finalized for delivery to DLA. The delivery is expected to take place before the end of November.

II.2 Development of User Interface

The implementation of the user interface for the UNIX and DOS versions of the FDAS is now complete. A minor problem pertaining to suppression of a few of error messages (UNIX version) persists and needs resolving. The user interface for the Sewing Defects Analysis System (SDAS) continues to remain in "development" because of the incomplete nature of the underlying knowledge base. The final restructuring and implementation of the user interface for the SDAS will be delayed until SDAS software takes its final shape.

II.3 Software Implementation of Sewing Defects

The task of software generation for the analysis of sewing defects continues to be the main focus of the research team. About 70% of software development has been completed so far. Information gathered from several different sources (apparel experts, textbooks, technical journals and research papers) is being further discussed and finalized before converting the same into software.

II.4 Database Structuring

Having tried very hard to get Nexpert to communicate with the Oracle database and failed, database integration has been deferred until the implementation of SDAS is complete.

The developers of Nexpert software have run into further problems with their database interface. This, in turn, has seriously affected the schedule of the research team. Efforts are being made to integrate the Oracle database with FDAS, using Nexpert.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. Plans for Next Month

III.1 Design of SDAS

Work will continue on the design and implementation of the Sewing Defects Analysis System. The system will also be continuously tested and refined as it takes its final shape.
IIII.2 Porting of SDAS Software

After the UNIX version of the SDAS software is completely implemented, it will be ported over for use on an MS-DOS machine.

IIII.3 Travel

Regular visits to Southern College of Technology are scheduled on a weekly basis. Mr. Bill Cameron and Mr. Howard Pettigrew are expected to contribute their knowledge and experience to enrich and simplify the knowledge base gathered by the research team.
### ANÁLISIS DE DEFECTOS EN LA FABRICACIÓN DE PANTALONES

#### PROGRAMA DE PLANIFICACIÓN

<table>
<thead>
<tr>
<th>FASE I</th>
<th>Desarrollo de Base de Conocimientos</th>
<th>Revisión de Literatura &amp; Selección de Expertos</th>
<th>Impacto Económico de los Defectos</th>
<th>Clasificación de Defectos</th>
<th>Structuración del Conocimiento</th>
<th>Establecimiento de Orígenes de Defectos</th>
<th>Identificación de Medidas para Defectos</th>
<th>Informe Técnico</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### FASE II

**Análisis & Desarrollo de Software**
- Desarrollar y enviar cuestionario
- Analizar respuestas del cuestionario
- Implementar en software
- Impacto económico industrial
- Desarrollar manual de software
- Desarrollar software de prueba
- Recopilar datos para otros artículos
- Informe Técnico

#### FASE III

**Reconstrucción & Extensión de Base de Conocimientos**
- Completar desarrollo de software
- Completar manual de software
- Desarrollar programa de entrenamiento
- Complete extended defects knowledge base (otros artículos)
- Analizar elección de metodología
- Informe Final & Demostración de Producto

---

**ANÁLISIS DE DEFECTOS EN LA FABRICACIÓN DE PANTALONES**

**PERIODO TERMINAL 10-31-90**
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for November

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in November 1988 and is being carried out in three phases. This report reviews the progress made during the month of November 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

1.3 Travel

This month’s travel activity was primarily confined to weekly visits to Southern College of Technology. The task of compiling causes and remedies for the whole range of cutting and sewing problems, in consultation with the AMTC apparel experts, has been completed this month.

During the Russell visit (please see Architecture and Procurement Project Reports), Dr. Jayaraman made a presentation on the defects project. FDAS was subsequently demonstrated on an IBM PS/2 machine and evoked positive interest from the participants.
II. Research Status

II.1 Fabric Defects Analysis System

The software for the Fabric Defects Analysis System (DOS version) is now ready for delivery. This software has been ported from UNIX to DOS version and successfully tested in the laboratory. However, the delivery of the FDAS software is awaiting the completion of the user’s manual.

II.2 Development of User Interface

The problems that remained to be solved in suppressing error messages in the implementation of the user interface have been solved. The user interface is now fully integrated with FDAS and works as desired.

II.3 Software Implementation of Sewing Defects

The task of software generation for the analysis of sewing defects continues to be the main focus of the research team. About 85% of software development has been completed so far. Information gathered from several different sources (apparel experts, textbooks, technical journals and research papers) is being further discussed and finalized before converting the same into software.

The user interface for the Sewing Defects Analysis system (SDAS) has been built for the most part but is not completed yet because of the incomplete nature of the underlying knowledge base. The final restructuring and implementation of the user interface for SDAS will be delayed until the SDAS software takes its final shape.

II.4 Database Structuring

Due to the problems faced in arranging Nexpert to work with the Oracle database Program, database integration has been deferred until the implementation of SDAS is completed.
II.5  **Original Research Task Schedule**

A copy of the time-task schedule included in the original research proposal is attached.

**III. Plans for Next Month**

**III.1 Design and Implementation of SDAS**

Some minor changes in the design of SDAS, introduced recently have slowed down the pace of implementation of SDAS. However, the research team will strive to complete the implementation of the UNIX version of SDAS before the end of December. Testing and refinement of SDAS will proceed simultaneously.

**III.2 Porting of SDAS to DOS**

Porting of the UNIX version of SDAS to DOS version will be initiated as soon as the software is implemented on UNIX. No serious problem is expected in porting the SDAS software.

**III.3 Writing of User’s Manuals**

Work on compiling a user’s manual for the SDAS software will begin as soon as the FDAS manual is printed and delivered. User’s manual for the SDAS software can be expected to be ready by the time the software takes its final shape.

**III.4 Travel**

Two final visits have been scheduled to Southern College of Technology to discuss ways and means of handling certain defects that have the same basic causes and are known to cause additional defects with the passage of time. (e.g., Skipped stitches may lead to an open seam and raw edges may be the result of an open seam). Defects which are capable of deteriorating further to end up as some other defect will be discussed in the final meetings.
### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

**PROGRAM SCHEDULE**

**PERIOD ENDING 11-30-90**
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for December

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is a two-year effort funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of December 1990. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

1.3 Travel

The research team made two visits to Southern College of Technology and held discussions on the hierarchical structuring of defects originating from to the same basic causes.
II. Research Status

II.1 Fabric Defects Analysis System

The software for the Fabric Defects Analysis System (FDAS) has been successfully ported from UNIX to DOS version. The DOS version of the FDAS has been tested in the laboratory and is now ready for shipment. The user's manual for the FDAS software has also been completed and will be included in the software shipment.

II.2 Development of User Interface

The problems in suppressing error messages in the implementation of the user interface have been solved. The user interface is now fully integrated with the and works as desired.

II.3 Software Implementation of Sewing Defects

The task of software generation for the analysis of sewing defects continues to be the main focus of the research team. About 90% of software development has been completed so far. Information gathered from several different sources (apparel experts, textbooks, technical journals and research papers) is being used in developing the software.

The user interface for the Sewing Defects Analysis System (SDAS) has been built for the main part but is not completely done yet because of the incomplete nature of the underlying knowledge base. The final restructuring and implementation of the user interface for SDAS are now in progress.

II.4 Database Structuring

Due to the problems faced in arranging Nexpert to work with the Oracle database Planet database integration has been deferred until the implementation of SDAS is completed.

II.5 Demonstration

As part of the ACB, a tour of Tech research facilities was arranged. During this tour, visitors were given a brief demonstration of FDAS in the CIM lab in the School of Textile Engineering.

II.6 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.
III. Plans for Next Month

III.1 Design and Implementation of SDAS

Minor changes in the design of SDAS and reconfiguration of the network of UNIX computers used for software development, have temporarily delayed the implementation of SDAS software.

III.2 Porting of SDAS to DOS

Porting of the UNIX version of SDAS to DOS version will be initiated as soon as the software is implemented on UNIX. No serious problem is expected in porting the SDAS software.

III.3 Writing of User’s Manuals

Work on compiling a user’s manual for the SDAS software has been initiated. The manual will be ready by the time the software takes its final shape.

III.4 Travel

No travel is planned for the month of January 1991.
### CASE I
- Knowledge Base Development
  - Literature Review &
    - Selection of Experts
  - Economic Impact of defects
  - Classification of defects
  - Structuring of knowledge
  - Establishing origins of defects
  - Identifying remedies of defects
  - Technical Report

### CASE II
- Analysis & Software Development
  - Develop and mail questionnaire
  - Analyze questionnaire responses
  - Implement in software
  - Industry-wide economic impact
  - Develop software manual
  - Debug/field-test software
  - Gather data for other garments
  - Technical Report

### CASE III
- Refinement & Knowledge Base Extension
  - Complete software development
  - Complete software manual
  - Develop training program
  - Complete extended defects
    - Knowledge base (other garments)
  - Analyze Choice of methodology
  - Final Report & Demonstrate Software Product

---

**ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE**

**PERIOD ENDING 12-31-90**
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. Project Review for January through March, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the months of January through March, 1991. It also outlines the work to be carried out in the coming quarter. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

I.3 Travel

One trip was made to the Southern College of Technology during March, to discuss the structure of the database schema for recording defect occurrences in the Sewing Defects Analysis System (SDAS).

Dr. Jayaraman made a presentation on the research endeavor at the 1991 Annual Apparel Academic Researchers Conference in Clemson, South Carolina.
II. Research Status

II.1 Software Implementation of Sewing Defects (on UNIX)

The arrival of a new and more powerful Sun Workstation in early January, necessitated major changes in the network of research computers. The network is now re-configured and fully operational.

The status of SDAS has reached about 95% completion; progress has also been made on upgrading the interface for the SDAS. The interface on the UNIX system is currently under design, and a few components have already been developed. Others developed for FDAS are being modified for use with SDAS. It is important that what the user sees on screen must be very simple and robust, to bear up under continuous use by plant personnel who have little time to spend in either learning about the system or using it on a day-to-day production basis. At the same time, each inspection station must be capable of doing garment inspection and defect diagnosis on a stand-alone basis, as well as communicate defect information with a centralized database as and when necessary. The current user interface is being developed on Sun workstations, using the Open Look standards layered on top of the X11 window system. The user interface will continue to change in minor aspects as the structure of SDAS gets finalized.

II.2 Software Implementation of Sewing Defects (on DOS)

The porting of SDAS software to DOS has commenced. Problems initially arose with the Microsoft QuickC compiler when attempts were made to get some of SDAS' ancillary programs and external handlers (written in C) to a working state. These problems basically concern DOS's memory restrictions, but have since been overcome.

The transfer of the bulk of the SDAS software has proceeded smoothly since then, and a Nexpert Forms interface (similar to the one used for FDAS) is under development. Most of SDAS can now run on the DOS delivery platform, and should be on par with the UNIX version by mid-April.

II.3 Database Integration with SDAS System (on UNIX)

The major problems encountered in connecting the SDAS software (written in Nexpert) to the Oracle database system have been overcome. Complete integration with the defects classification and analysis rules is now in full swing, and no further large implementation obstacles are likely.

With the help of consultants from Southern Tech, suitable general database schemas for the Oracle database have been drawn up. These will be sufficient for 90% of the industry's needs, in terms of important defect information and tracking data useful on the shop-floor and in technical management or quality control. Further customization of database layout can be done by individual organizations, if necessary.

The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and aims to collect/transmit information from/to multiple sessions of the SDAS system. However, the current prototype being tested concentrates on the smooth and cohesive working of a single SDAS process front-ending the database.

II.4 Database Integration with FDAS System (on UNIX)

Having overcome the earlier generic problems plaguing Nexpert-Oracle connectivity, work on
database linkages for the Fabric Defects Analysis System (FDAS) is in progress. Basic defect data addition to the cumulative database has already been accomplished. The current effort concentrates on trying to identify the 3-4 major types of defect reports and summarized tabulations (output forms) that would be beneficial to a generic fabric manufacturer. (Of course, additional special defect report templates can be developed using Oracle's own software tools, by any user of FDAS).

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. Plans for Next Quarter

III.1 Design and Implementation of SDAS (on UNIX)

It is hoped that, but for the user interface and database links, the implementation will be completed by the end of April. Further additions will be made to the SDAS knowledge base specifically dealing with trim defects (zippers, thread, buttons, etc.) as well as folding/finishing problems. The software will also have references to some of the major fabric defects. However, this will only be for defect tracking purposes. There is no need for detailed classification or analysis of fabric defects in SDAS, since this is taken care of by FDAS.

Once the structure and content of SDAS are 'frozen', the windowing user interface will take up another two to three weeks of intensive development. This will be X11-based graphical front-end compliant with Open Look standards. While this version will run only on Sun workstations, minor modifications will get it to work on any X-based terminal or display. Since the UNIX version is not the delivery vehicle, the research team will not concentrate on polishing the user interface to perfection. It is meant more for demonstration purposes, especially to show off the multiple-session possibilities (with a single common defects database) on a UNIX platform.

III.2 Porting of SDAS software (to DOS)

Work on porting SDAS to DOS will be continued.

III.3 Database Integration with SDAS software (UNIX)

Work on integrating the developed database schemas with Nexpert rules and communication processes to transfer defect data to the database will be continued. A few of the most necessary and useful defect summaries and database reports will also be prepared; this work will be completed after the work on SDAS and its user interface are completed.

At that point, a single version of SDAS, closely tied to the Oracle database, will be in demonstrable form and ready for testing as a joint system.

III.4 Database Integration with SDAS software (DOS)

This step will be taken after the Nexpert Forms interface is developed on the DOS platform. As with the co-existence of any large applications on this operating system, the simultaneous working of both Nexpert Object and the Oracle DBMS is likely to be a difficult task -- problems in process isolation and memory management may surface. However, efforts will be made to get a single
SDAS session working in tandem with the Oracle database before the end of the project.

III.5 Testing of SDAS (UNIX and DOS)

Messrs. Bill Cameron and Howard Pettigrew from Southern Tech are expected to test the functionality of SDAS in the near future, on Georgia Tech's UNIX development machines. This will be extensive validation of SDAS' contents as regards technical accuracy and completeness of coverage, undertaken in two or three sessions of a few hours each. This will be in addition to the research team's own verification and testing of the SDAS software as it is being developed.

III.6 Writing of User's Manuals

Work on creating documents to detail the user level view of the FDAS and SDAS software has been initiated. Now that the database inclusion into FDAS is nearing completion, this permits a clear understanding of most of the user interface issues for that system. The FDAS manual will outline the different ways the user can use FDAS, with or without recording defects data into the Oracle database, using the fast classification panel for familiar defects, etc.

The SDAS manual will be written after the FDAS instructions are complete. The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

III.7 Writing of the Final Project Report

Work will be initiated on writing the Final Project Report.

III.8 Travel

At least two or three more trips to Southern College of Technology will be required for discussion sessions to wrap up the final decisions to be made regarding the design and use of SDAS. It is also possible that there will be a demonstration of SDAS at Southern Tech open to the industry, which will provide invaluable industrial feedback on the features and functionality of the software system.
### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERIOD ENDING 03-31-91
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

Project Review for April through June, 1991

I. SUMMARY

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the months of April through June, 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Krishna Parachuru and Dr. Phiroze Dastoor are the Research Investigators. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

1.3 Travel

Dr. Jayaraman discussed the project with a few of the participants while attending the AAMA Government Contracts Committee in Hilton Head, South Carolina.
II. RESEARCH STATUS

II.1 Software Implementation of Sewing Defects (on UNIX)

The software implementation of SDAS on the UNIX operating system is nearly complete.

II.2 Software Implementation of Sewing Defects (on DOS)

The porting of SDAS software to DOS is nearly complete. Initial problems with the Microsoft QuickC compiler were overcome and the system appears to be robust.

A Nexpert Forms interface (similar to the one used for FDAS) has been developed. SDAS on the DOS delivery platform is on par with the UNIX version.

II.3 Database Integration with SDAS System (on UNIX)

The major problems encountered in connecting the SDAS software (written in Nexpen) to the Oracle database system have been overcome. Integration with the defects classification and analysis rules is nearly complete.

The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and aims to collect/transmit information from/to multiple sessions of the SDAS system. However, the current prototype being tested concentrates on the smooth and cohesive working of a single SDAS process front-ending the database.

II.4 Database Integration with FDAS System (on UNIX)

Having overcome the earlier generic problems plaguing Nexpert-Oracle connectivity, work on database linkages for the Fabric Defects Analysis System (FDAS) is in progress. Work on identifying the major types of defect reports and summarized tabulations (output forms) that would be beneficial to a generic fabric manufacturer has been continuing.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT QUARTER

III.1 Design and Implementation of SDAS (on UNIX)

Work on further additions to the SDAS knowledge base specifically dealing with trim defects (zippers, thread, buttons, etc.) as well as folding/finishing problems will be continued. The software will also have references to some of the major fabric defects. However, this will only be for defect tracking purposes. There is no need for detailed classification or analysis of fabric defects in SDAS, since this is taken care of by FDAS.

Once the structure and content of SDAS are 'frozen', the windowing user interface will take up another two to three weeks of intensive development. This will be X11-based graphical front-end compliant with Open Look standards. While this version will run only on Sun workstations, minor modifications will get it to work on any X-based terminal or display. Since the UNIX
version is not the delivery vehicle, the research team will not concentrate on polishing the user interface to perfection. It is meant more for demonstration purposes, especially to show off the multiple-session possibilities (with a single common defects database) on a UNIX platform.

III.2 Porting of SDAS software (to DOS)

Work on porting SDAS to DOS will be completed.

III.3 Database Integration with SDAS software (UNIX)

Remaining work on integrating the developed database schemas with Nexpert rules and communication processes to transfer defect data to the database will be continued.

III.4 Database Integration with SDAS software (DOS)

This step will be taken after the Nexpert Forms interface is developed on the DOS platform. As with the co-existence of any large applications on this operating system, the simultaneous working of both Nexpert Object and the Oracle DBMS is likely to be a difficult task -- problems in process isolation and memory management may surface. However, efforts will be made to get a single SDAS session working in tandem with the Oracle database before the end of the project.

III.5 Writing of User's Manuals

Work on creating documents to detail the user level view of the FDAS and SDAS software will be continued. The FDAS manual will outline the different ways the user can use FDAS, with or without recording defects data into the Oracle database, using the fast classification panel for familiar defects, etc.

The SDAS manual will be written after the FDAS instructions are complete. The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

III.6 Writing of the Final Project Report

Work will continue on writing the Final Project Report.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR JULY, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of July 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Phiroze Dastoor is the Research Investigator, while Dr. Krishna Parachuru served as one until recently. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

I.3 Travel

No travel was made specifically for this project.
II. RESEARCH STATUS

II.1 Software Implementation of Sewing Defects (on UNIX)

The software implementation of SDAS on the UNIX operating system has been completed. However, addition of further details regarding packing and folding defects may continue during the testing stage.

II.2 Software Implementation of Sewing Defects (on DOS)

The porting of SDAS software to DOS is also complete. The system is now being thoroughly tested and the user interface (which uses Nexpert forms) is receiving final touches. SDAS on the DOS delivery platform is on par with the UNIX version.

II.3 Database Integration with SDAS System (on UNIX)

The SDAS software (written in Nexpert) has been finally integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system. However, the current prototype being tested concentrates on the smooth and cohesive working of a single SDAS process front-ending the database.

II.4 Database Integration with FDAS System (on UNIX)

This task has also been completed. The Oracle database system keeps track of defect records generated by the FDAS software. However, in terms of examining these database tables to extract useful information, work is continuing on identifying the major types of defect reports and summarized tabulations (output forms) that would be beneficial to a generic fabric manufacturer.

II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.
III. PLANS FOR NEXT MONTH

III.1 Design and Implementation of SDAS (on UNIX)

Work on further additions to the SDAS knowledge base specifically dealing with trim
defects (zippers, thread, buttons, etc.) as well as folding/finishing problems will be
continued.

The software will also have references to some of the major fabric defects. However,
this will be applicable only for defect tracking purposes, since detailed classification or
analysis of fabric defects is taken care of by FDAS.

The development of an Open Windows windowing user interface is already well
underway, with a scheduled time of completion around the middle of August. This will be
a X11-based graphical front-end compliant with Open Look standards which will run on any
Sun workstation, and will require only minor modifications to get it to work on any X-based
terminal or display. Since the UNIX version is not the delivery vehicle, the research team
will only polish this user interface as far as time allows. It is meant more for demonstration
purposes, primarily to show off the multiple-session possibilities (with a single common
defects database) on a UNIX platform.

III.2 Database Integration with SDAS software (UNIX)

The database link from the SDAS software written on Nexpert is now functional.
Features such as one or two types of database reports are considered. These reports will be
working templates suitable for examining the contents of the database and extract defect
statistics by week or other time period, by operative, by style, etc.

III.3 Database Integration with SDAS software (DOS)

A Nexpert Forms interface has been developed on the DOS platform, as a visual
front-end for the SDAS system. Attempts are underway to get this combined software to
communicate with the Oracle DBMS, as already accomplished on the UNIX system. As with
the co-existence of any large applications on DOS, the simultaneous working of both
Nexpert Object and the Oracle DBMS is proving to be a somewhat difficult task. The
research team is currently having problems in process isolation and memory management.
However, with the help of technical advice from the developers of Nexpert Object (Neuron
Data, Inc.), an effort is being made to get a single SDAS session working in tandem with
the Oracle database.
III.4 Writing of User's Manuals

The FDAS user manual is 90% complete; it outlines the different ways the user can use FDAS on the DOS platform but currently does not address the recording of defects data into the Oracle database (since that work is to be finished for both FDAS and SDAS).

The SDAS manual is currently being written. The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

III.5 Writing of the Final Project Report

Work will continue on writing the final project report.
# Analysis of Defects in Trouser Manufacturing Program Schedule

**Period Ending 7-31-91**
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR AUGUST, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of August 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Phiroze Dastoor is the Research Investigator, while Dr. Krishna Parachuru served as one until recently. Mr. K. Srinivasan is the Graduate Research Assistant on the project.

I.3 Travel

No travel specifically for this project occurred during August.
II. RESEARCH STATUS

II.1 Software Implementation of Sewing Defects (on UNIX)

The software implementation of SDAS on the UNIX operating system has been completed. However, addition of further details regarding packing and folding defects may continue during the testing stage. The X11-based graphical user interface has now achieved a good level of functionality. Using this graphics front-end to SDAS allows several sessions of SDAS to be run on different networked machines, each communicating over TCP/IP with a common global Oracle database for the purpose of recording defect occurrences. This demonstrates a distributed processing capability, which is very important in actual shop-floor inspection.

II.2 Software Implementation of Sewing Defects (on DOS)

The porting of SDAS software to DOS is complete. The system has been tested, and the user interface is complete.

II.3 Database Integration with FDAS and SDAS Systems (on UNIX)

The SDAS software (written in Nexpert) has been fully integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system.

Similarly, FDAS also uses the Oracle database system to keep track of the defect data it generates.

II.4 Database Integration with FDAS and SDAS Systems (on UNIX)

Nexpert Forms interfaces have been developed on the DOS platform, as visual front-ends for the two software systems. Both FDAS and SDAS now communicate with the Oracle DBMS for writing defect records, as already accomplished on the UNIX system. However, only single sessions of each system can interact with a single copy of Oracle running on the same DOS computer.
II.5 Writing of User Manuals

Both user manuals are 90% complete. They outline the different ways the user can use FDAS and SDAS on the DOS platform but currently do not address the recording of defects data into the Oracle database (since that work has just been finished for both FDAS and SDAS).

The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

II.6 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

III.1 Design and Implementation of SDAS (on UNIX and DOS)

Work on further additions to the SDAS knowledge base specifically dealing with trim defects (zippers, thread, buttons, etc.) as well as folding/finishing problems will be continued.

The software will also have references to some of the major fabric defects. However, this will be applicable only for defect tracking purposes, since detailed classification or analysis of fabric defects is taken care of by FDAS.

III.2 Database Integration with FDAS and SDAS software (UNIX)

While the database link from the SDAS software written on Nexpert is now functional, addition of features such as one or two types of database reports are being considered. These reports will be working templates suitable for examining the contents of the database and extract defect statistics by week, by operative, by style, etc.
III.3 Writing of User's Manuals

The FDAS and SDAS user manuals have to be updated with information on using the Oracle database in tandem with the main FDAS/SDAS software, for recording defects data.

III.4 Writing of the Final Project Report

Work will continue on writing the Final Project Report.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERIOD ENDING 8-31-91

<table>
<thead>
<tr>
<th>MONTH</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I</td>
<td>KNOWLEDGE BASE DEVELOPMENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Literature Review &amp; Selection of Experts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Economic Impact of Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Classification of Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structuring of Knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Establishing Origins of Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE II</td>
<td>ANALYSIS &amp; SOFTWARE DEVELOPMENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop and Mail Questionnaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze Questionnaire Responses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Implement Software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industry-wide Economic Impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop Software Manual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Setup/Field -test Software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gather Data for Other Garments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE III</td>
<td>REFINEMENT &amp; KNOWLEDGE BASE EXTENSION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete Software Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete Software Manual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop Training Program</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete Extended Defects Knowledge Base (Other Garments)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of Methodology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR OCTOBER, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of October 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Phiroze Dastoor is the Research Investigator, while Dr. Krishna Parachuru served as one until recently. Mr. K. Srinivasan has been the Graduate Research Assistant on the project.

I.3 Travel

None specifically for this project.
II. RESEARCH STATUS

II.1 Fabric Defects Analysis System (FDAS) and Sewing Defects Analysis System (SDAS)

Both systems are ready for delivery to DLA.

II.2 Database Integration with FDAS and SDAS Systems (on UNIX)

The SDAS software (written in Nexpert) has been fully integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system.

Similarly, FDAS also uses the Oracle database system to keep track of the defect data it generates.

II.3 Writing of User Manuals

Both user manuals are 95% complete. They outline the different ways the user can use FDAS and SDAS on the DOS platform but have yet to incorporate instructions regarding the recording of defects data into the Oracle database (since that work has just been finished for both FDAS and SDAS).

The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

II.4 Acceptance of Paper for Publication in Journal

The Journal of the Textile Institute, a leading refereed journal in the textile field, recently accepted a paper entitled FDAS: A Knowledge-based Framework for the Analysis of Defects in Woven Textile Structures submitted for publication by members of the research team. The paper discusses the need for and characteristics of the fabric defects analysis system.
II.5  **Original Research Task Schedule**

A copy of the time-task schedule included in the original research proposal is attached.

III.  **PLANS FOR NEXT MONTH**

III.1  **Writing of User's Manuals**

The FDAS and SDAS user manuals have to be updated with information on using the Oracle database in tandem with the main FDAS/SDAS software, for recording defects data.

III.2  **Writing of the Final Project Report**

Work will continue on writing the Final Project Report.
# Analysis of Defects in Trouser Manufacturing Program Schedule

**Period Ending: 10-31-91**

## Phase I
### Knowledge Base Development
- Literature Review & Selection of Experts
- Economic Impact of Defects
- Classification of Defects
- Structuring of Knowledge
- Establishing Origins of Defects
- Identifying Remedies of Defects
- Technical Report

## Phase II
### Analysis & Software Development
- Develop and Mail Questionnaire
- Analyze Questionnaire Responses
- Implement Software
- Industry-wide Economic Impact
- Develop Software Manual
- Setup/Field-test Software
- Gather Data for Other Garments
- Technical Report

## Phase III
### Refinement & Knowledge Base Extension
- Complete Software Development
- Complete Software Manual
- Develop Training Program
- Complete Extended Defects Knowledge Base (Other Garments)
- Analyze Choice of Methodology
- Final Report & Demonstrate Software Product
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR NOVEMBER, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

1.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of November 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

1.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Drs. Phiroze Dastoor and Krishna Parachuru were the Research Investigators on the project. Mr. K. Srinivasan has been the Graduate Research Assistant on the project.

1.3 Travel

No travel was conducted specifically for this project.
II. RESEARCH STATUS

II.1 Fabric Defects Analysis System (FDAS) and Sewing Defects Analysis System (SDAS)

Both systems are ready for delivery to DLA.

II.2 Database Integration with FDAS and SDAS Systems (on UNIX)

The SDAS software (written in Nexpert) has been fully integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system.

Similarly, FDAS also uses the Oracle database system to keep track of the defect data it generates.

II.3 Writing of User Manuals

Both user manuals are nearly complete. They outline the different ways the user can use FDAS and SDAS on the DOS platform but have yet to incorporate instructions regarding the recording of defects data into the Oracle database (since that work was only recently completed for both FDAS and SDAS).

The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

II.4 Acceptance of Paper for Poster Presentation at the Fiber Society Technical Conference

The paper entitled FDAS: A Knowledge-based Framework for the Analysis of Defects in Woven Textile Structures accepted recently for publication by Journal of the Textile Institute, a leading refereed journal in the textile field, has been accepted for presentation at a Poster Session during the upcoming Fiber Society Technical Conference to be held in New Orleans, LA. The paper discusses the need for and characteristics of the fabric defects analysis system.
II.5 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

III.1 Writing of User’s Manuals

The FDAS and SDAS user manuals have to be updated with information on using the Oracle database in tandem with the main FDAS/SDAS software, for recording defects data.

III.2 Writing of the Final Project Report

Work will continue on writing the Final Project Report.
## Analysis of Defects in Trouser Manufacturing Program Schedule

**Period Ending:** 11-30-91

### Phase I: Knowledge Base Development
- Literature Review & Selection of Experts
- Economic Impact of Defects
- Classification of Defects
- Structuring of Knowledge
- Establishing Origins of Defects
- Identifying remedies of Defects
- Technical Report

### Phase II: Analysis & Software Development
- Develop and Mail Questionnaire
- Analyze Questionnaire Responses
- Implement Software
- Industry-wide Economic Impact
- Develop Software Manual
- Setup/Field-test Software
- Gather Data for Other Garments
- Technical Report

### Phase III: Refinement & Knowledge Base Extension
- Complete Software Development
- Complete Software Manual
- Develop Training Program
- Complete Extended Defects Knowledge Base (Other Garments)
- Analyze Choice of Methodology
- Final Report & Demonstrate Software Product
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR DECEMBER, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of December 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Drs. Phiroze Dastoor and Krishna Parachuru were the Research Investigators on the project. Mr. K. Srinivasan has been the Graduate Research Assistant on the project.

I.3 Travel

Mr. K. Srinivasan presented a poster entitled FDAS: A Knowledge-based Framework for the Analysis of Defects in Woven Textile Structures at the Fiber Society Technical Conference held in New Orleans, LA. The poster covered the need for and characteristics of the fabric defects analysis system.
II. RESEARCH STATUS

II.1 Fabric Defects Analysis System (FDAS) and Sewing Defects Analysis System (SDAS)

Both systems are ready for delivery to DLA.

II.2 Database Integration with FDAS and SDAS Systems (on UNIX)

The SDAS software (written in Nexpert) has been fully integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system.

Similarly, FDAS also uses the Oracle database system to keep track of the defect data it generates.

II.3 Final Technical Report

A draft of the final technical report has been submitted to DLA for review and comments.

II.4 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

III.1 Writing of User's Manuals

The FDAS and SDAS user manuals will be updated with information on using the Oracle database in tandem with the main FDAS/SDAS software, for recording defects data.

III.2 Writing of the Final Project Report

Work will continue on finalizing the Project Technical Report.
### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERIOD ENDING 12-31-91

<table>
<thead>
<tr>
<th>MONTH</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
</table>

**PHASE I**

**KNOWLEDGE BASE DEVELOPMENT**

- Literature Review & Selection of Experts
- Economic Impact of Defects
- Classification of Defects
- Structuring of Knowledge
- Establishing Origins of Defects
- Identifying remedies of Defects
- Technical Report

**PHASE II**

**ANALYSIS & SOFTWARE DEVELOPMENT**

- Develop and Mail Questionnaire
- Analyze Questionnaire Responses
- Implement Software
- Industry-wide Economic Impact
- Develop Software Manual
- Setup/Field-test Software
- Gather Data for Other Garments
- Technical Report

**PHASE III**

**REFINEMENT & KNOWLEDGE BASE EXTENSION**

- Complete Software Development
- Complete Software Manual
- Develop Training Program
- Complete Extended Defects Knowledge Base (Other Garments)
- Analyze Choice of Methodology
- Final Report & Demonstrate Software Product
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR JANUARY, 1992

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of January 1992. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Drs. Phiroze Dastoor and Krishna Parachuru were the Research Investigators on the project. Mr. K. Srinivasan has been the Graduate Research Assistant on the project.

I.3 Travel

No project related travel occurred during January.
II. RESEARCH STATUS

II.1 Fabric Defects Analysis System (FDAS) and Sewing Defects Analysis System (SDAS)

Both systems are ready for delivery to DLA.

II.2 Database Integration with FDAS and SDAS Systems (on UNIX)

The SDAS software (written in Nexpert) has been fully integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system.

Similarly, FDAS also uses the Oracle database system to keep track of the defect data it generates.

II.3 Final Technical Report

A draft of the final technical report has been submitted to DLA for review and comments.

II.4 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

III.1 Writing of the Final Project Report

Work will continue on finalizing the Project Technical Report.
### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

**PERIOD ENDING 1-31-92**

<table>
<thead>
<tr>
<th>PHASE I</th>
<th>KNOWLEDGE BASE DEVELOPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Literature Review &amp; Selection of Experts</td>
</tr>
<tr>
<td></td>
<td>Economic Impact of Defects</td>
</tr>
<tr>
<td></td>
<td>Classification of Defects</td>
</tr>
<tr>
<td></td>
<td>Structuring of Knowledge</td>
</tr>
<tr>
<td></td>
<td>Establishing Origins of Defects</td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of Defects</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>ANALYSIS &amp; SOFTWARE DEVELOPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Develop and Mail Questionnaire</td>
</tr>
<tr>
<td></td>
<td>Analyze Questionnaire Responses</td>
</tr>
<tr>
<td></td>
<td>Implement Software</td>
</tr>
<tr>
<td></td>
<td>Industry-wide Economic Impact</td>
</tr>
<tr>
<td></td>
<td>Develop Software Manual</td>
</tr>
<tr>
<td></td>
<td>Setup/Field -test Software</td>
</tr>
<tr>
<td></td>
<td>Gather Data for Other Garments</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>REFINEMENT &amp; KNOWLEDGE BASE EXTENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete Software Development</td>
</tr>
<tr>
<td></td>
<td>Complete Software Manual</td>
</tr>
<tr>
<td></td>
<td>Develop Training Program</td>
</tr>
<tr>
<td></td>
<td>Complete Extended Defects Knowledge Base (Other Garments)</td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of Methodology</td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software Product</td>
</tr>
</tbody>
</table>
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR FEBRUARY, 1992

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of February 1992. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Drs. Phiroze Dastoor and Krishna Parachuru were the Research Investigators on the project. Mr. K. Srinivasan has been the Graduate Research Assistant on the project.

I.3 Travel

No travel occurred during the month of February.
II. RESEARCH STATUS

II.1 Fabric Defects Analysis System (FDAS) and Sewing Defects Analysis System (SDAS)

Both systems are ready for delivery to DLA.

II.2 Final Project Report

The draft of the technical report has been approved by DLA. The report has since been edited. The report is in three volumes. They are:

Volume I: Final Technical Report (119 pages)
Volume II: FDAS User Manual (27 pages)
Volume III: SDAS User Manual (15 pages)

The report has been submitted to DLA.

II.4 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

The project goals have been accomplished and no further activities are planned on the project.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

PERIOD ENDING 2-28-92

<table>
<thead>
<tr>
<th>PHASE I</th>
<th>KNOWLEDGE BASE DEVELOPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Literature Review &amp; Selection of Experts</td>
</tr>
<tr>
<td></td>
<td>Economic Impact of Defects</td>
</tr>
<tr>
<td></td>
<td>Classification of Defects</td>
</tr>
<tr>
<td></td>
<td>Structuring of Knowledge</td>
</tr>
<tr>
<td></td>
<td>Establishing Origins of Defects</td>
</tr>
<tr>
<td></td>
<td>Identifying remedies of Defects</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>ANALYSIS &amp; SOFTWARE DEVELOPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Develop and Mail Questionnaire</td>
</tr>
<tr>
<td></td>
<td>Analyze Questionnaire Responses</td>
</tr>
<tr>
<td></td>
<td>Implement Software</td>
</tr>
<tr>
<td></td>
<td>Industry-wide Economic Impact</td>
</tr>
<tr>
<td></td>
<td>Develop Software Manual</td>
</tr>
<tr>
<td></td>
<td>Setup/Field-test Software</td>
</tr>
<tr>
<td></td>
<td>Gather Data for Other Garments</td>
</tr>
<tr>
<td></td>
<td>Technical Report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>REFINEMENT &amp; KNOWLEDGE BASE EXTENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete Software Development</td>
</tr>
<tr>
<td></td>
<td>Complete Software Manual</td>
</tr>
<tr>
<td></td>
<td>Develop Training Program</td>
</tr>
<tr>
<td></td>
<td>Complete Extended Defects Knowledge Base (Other Garments)</td>
</tr>
<tr>
<td></td>
<td>Analyze Choice of Methodology</td>
</tr>
<tr>
<td></td>
<td>Final Report &amp; Demonstrate Software Product</td>
</tr>
</tbody>
</table>
October 30, 1989

Ms. Sara Williams
Defense Electronics Supply Center
CO
Attn: PSC
1507 Wilmington Pike
Dayton, Ohio 45444-5208

SUBJECT: AMTC Monthly Reports
Performance Period: 090189-093089

Dear Ms. Williams:

Please find the captioned reports of Georgia Tech and Southern Tech activities for your review.

Cordially,

Susan Griffin
Associate Project Director
Apparel Manufacturing Technology Center

Attachments
rlg:

cc: John Adams, Project Director
    Mr. Dan Gearing, COTR
SEPTEMBER MONTHLY REPORTS
APPAREL MANUFACTURING TECHNOLOGY CENTER

CONTRACT NUMBER: DLA900-87-D-0018
PERFORMANCE PERIOD: 890901 - 890930

Submitted by:
Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology

Sponsored by:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

October 20, 1989
TABLE OF CONTENTS

Section I: Technical Reports

Base Contract
Short Term Research Tasks

Section II: Data Accession List

Section III: Program Schedules

Base Contract
Short Term Research Tasks
SECTION I
PROGRAM MANAGEMENT AND REPORTING

Administrative

Measuring the Effectiveness of the AAMTDC and Cut Order Planning were funded during September.

All AMTC Researchers met on September 22 to finalize Annual Report and Contract Briefing preparations.

All advisory board and coalition members received an invitation to the Annual Contract Briefing.

Workshops

Registration confirmations were sent to October 11 workshop participants.

Workshop speakers are as follows:

Chuck Marsh, William Carter Company
Mike Biggerstaff, Health-Tex, Inc.
Becca McClendon, Kurt Salmon Associates
Joe Brefeld, U.S. Shoe Corp.
Tom Burchard, U.S. Shoe Corp.

In addition to the presentations, Health-Tex and KSA will have video footage of real-world modular groups in action.

AMTC will feature a modular system in the pilot plant during the afternoon session of the workshop. The demonstration will include the manufacture of AMTC's utility trousers as well as a modular unit producing camp shorts. H.D. Lee loaned AMTC the necessary equipment to set up the modular system.

Presentations and Industry Events

Wayne Tincher and John Adams made a presentation about AMTC and its research efforts during a Bobbin Show session.

Georgia Tech and Southern Tech publicized AMTC to industry and alumni in its booth at the Bobbin Show. The booth was sponsored in conjunction with the Georgia Textile Education Foundation, who also recruits students at the show.
OUTREACH

The September issue of the AMTC Quarterly was distributed to 1600 industrialists on the AMTC mailing list as well as Bobbin Show attendees.

Work is continuing on the video about the Generic Architecture project.

A new Georgia Tech publication was completed during September. Success Stories: Georgia Tech Around the State describes many industry assistance projects in which Georgia Tech has engaged. One section is devoted to work in the textile and apparel industry and includes information about AMTC. Success Stories will be sent to various industry executives and university advocates to promote Georgia Tech programs. Copies of the publication are available upon request.

Georgia Tech is conducting a project for the Georgia Appalachian Regional Commission. The purpose is to determine the level of technology currently employed by apparel manufacturers in the North Georgia area. Susan Griffin is working on the project which includes the development of a questionnaire and "scoring" system. These products will be available for AMTC's use in future industry outreach/assistance projects.
DEMONSTRATION PLANT OPERATIONS

Demonstrations

Tom Heckman, Department of Commerce, visited AMTC on September 20.

Six international representatives of Coats & Clark toured AMTC.

More than 30 students from Southern Tech’s Manufacturing Methods classes participated in an in-depth tour and demonstration at the center. Many Industrial Engineering classes are utilizing the facilities to familiarize students with apparel manufacturing technology and provide hands-on experience in a manufacturing environment.

Aaron Efrid, Vice President of Seagoing Uniforms, and two of his plant managers toured AMTC and discussed manufacturing methods demonstrated and their application to operations at Seagoing.

Other visitors are noted on the Data Accession List.

Equipment

Two representatives of PROFEEL visited the center and demonstrated their pneumatic ply alignment device and pneumatic floatation positioning device for seaming. The former will be used to seam shorts in the modular unit. The latter will be adapted to the YKK zipper machine to aid in the placement of the flies.

Sharon Palmer of BZA met with technicians to discuss installing and training on the KARAT software. This should occur during the next two months.

Hewlett Packard met with AMTC staff members to discuss implementation of computer network for AMTC’s computer integrated manufacturing system. This network should be operational at the December workshop.

During the Bobbin Show, several contacts were made which resulted in the acquisition of a Brother BAS 350 and a Reece Pocket Welt Machine.

Student Projects

The Department Head of Southern Tech’s Computer Science Department met with AMTC staff members to discuss student projects. Two projects have been identified: computer program modifications for ACS and modifications for Gerber Garment Technology (CAD) system. Computer Science students are currently working on the ACS project. Future projects were also discussed.
ACS Computer Systems Operation

Reloading of the ACS software was completed September 12. An update to the existing software was also attempted, however, AS400 memory capacity was not sufficient.

Roy Wendell of ACS met with Southern Tech staff members and students during the Bobbin Show. Problems associated with the software's handling of multiple bundle sizes per style were discussed. It is generally felt that the software can be modified to manage the multiple bundle concept, and a design revision will be undertaken to alleviate the problem. Three Southern Tech students have been assigned to the project.
RESEARCH

Design and Development of a Generic Architecture - Industry interest in this project continues. AAMA's CIM/COM Committee has established a new sub-committee to review the architecture project. A copy of the model was sent to Dan Wilson, Chairman of the sub-committee.

Work is continuing on a 20 minute video describing the project. The document is being developed for DLA, however, researchers will also use it to publicize the project.

Work is continuing on the information architecture; the first version is expected to be completed by the end of October.

Knowledge-Based Framework for Trouser Procurement - Statistical analysis of questionnaire data continues. Because of the modest response, researchers are determining areas where additional information must be obtained to ensure validity of the study.

Analysis of Defects - The first prototype for fabric defects analysis is nearing completion. Researchers are developing a scheme for classification of sewing defects. The classification will be along the lines of the one developed for the classification of fabric defects. Efforts will be made to visit Coastal Industries and other apparel manufacturers to gather more information on defects. Because of the modest response, researchers are determining areas where additional information must be obtained to ensure validity of the study.

Discrete Event Simulation - Work continues to focus on the generic discrete event simulation model of a trousers plant, using the parts flow configuration of the AMTC pilot plant. Activities during September revolved around the center and its Mr. Engineer software. Technicians have been studying unit processing times for operations to manufacture the utility trousers.

Researchers are also preparing for the December 5 workshop where the model will be introduced to industry as well as students. The project will be completed by the end of the year.

Ergonomic Principles - The first phase of the project was completed in September. Anthropometric data and interview data from 3 plant sites were summarized and presented in the Phase I Report.

If possible, additional data will be collected at other plants during Phase II.

Next month, researchers will test possible solutions to problems identified in Phase I.
In-Process Quality Control: Fabric Defects - Color data has been collected on denim fabric. Thirty samples of trouser fabric have been received and will serve as the basis for an automatic inspection system. Data is currently being analyzed.

In-Process Quality Control: Sewing Defects - Working on another Georgia Tech project, Lew Dorrity visited several Japanese apparel manufacturers in September. He was able to discuss the sewing defects project with them, particularly the area of transducing signals and their approaches to the problem.

Matt Sikorski continued his efforts to debug subroutines on the CRATE data collection equipment.

Next month, the team plans a trip to Coastal Industries to review the defects list and possible additions/revisions.

Improved Marker Making Systems - Previous correspondence with all companies was followed up by telephone. Contacts were found and agreements for participation in the project were formed with the following companies:

- Gerber Garment Technology
- Microdynamics, Inc.
- Polygon Software Co.
- CDI Technologies, Inc.

An outline of the vendor questionnaire was started. The types of information that will be solicited include (1) users of the system, (2) cost factors in developing the system, (3) technical abilities of the system, and (4) ideas and views on improvements and/or automation of marker systems in general. This questionnaire was put on hold due to questions that arose regarding the economic feasibility study.

Next month, researchers will enlist the assistance of AMTC's Dr. William B. Riall in conducting the economic feasibility study.

The literature search will be completed and reviewed in two areas:
1. Examination of the underlying "cutting stock problem" in industrial engineering and related journals, and
2. Examination of existing economic justification techniques in the apparel industry and how they can be applied to marker making systems.

Researchers will request from participating vendors any brochures, manuals, or other printed information about their existing marker making system. Demonstration diskettes will also be requested if available.
Flexible Work Group Methods - On-line literature search for relevant information regarding Flexible Work Groups (FWG) was begun.

Mike Brown conducted a tour of the demonstration center for two project team members, John Bartholdi from the School of Industrial and Systems Engineering (ISyE), and Richard Carey from the Economic Development Laboratory (EDL). Although none of the equipment was demonstrated, they were able to see and obtain information about the computing facilities and the manufacturing area.

Mike Brown attended the breakfast held by the Technical Advisory Committee of AAMA at the Bobbin Show. The presentation was entitled "Making the Revolution Work: How to Implement Flexible Apparel Manufacturing Through People." He collected a copy of this report for AMTC files.

Next month, a meeting of the entire project team will be held. The purpose is to discuss orientation, project plans, and answer questions, etc. Project members will also attend the Modular Manufacturing Workshop and the Annual Contract Briefing at Southern Tech.

Researchers will review and evaluate equipment in the Interactive Design and Analysis Laboratory for possible needed upgrades and/or additional purchases required for the VME. The team will also explore Georgia Tech funding sources for additional equipment.

Specifications will be made for the local area network hardware and software to be implemented in the Interactive Design and Analysis Lab.

Researchers will identify research issues and models relevant to the concept of flexible work groups. These will be used in the continuing literature search and review.

Initial plans for site visits will be made. Researchers want to observe current work methods and gather relevant information for the emulation of flexible work groups.

Measuring the Effectiveness of AAMTDC - Project Initiation Package and Deliverables Schedule were received. A kick-off meeting will be held October 27 at Southern Tech to discuss visitor classification system, development of technological base line, implementation of other measurement systems, and coordination with equipment vendors and military agencies for data collection purposes.
SECTION II
DATA ACCESSION LIST
SEPTEMBER 1989

Bassett Walker
Martinsville, VA

Dennis Beasley
Systecon
Duluth, GA

Dan Blitch
Chandon Ltd
Thomson, GA

Kyle Bortnight
Shaw Company
Dalton, GA

Jeremy Branne
J & P Coats (Caribbean) Ltd.
Trinidad

Gary Brasherid
I.C. Isaacs & Co.
Carthage, MS

Jim Bray
J.W. Bray Co.
Soddy Daisy, TN

J.W. Bray, Jr.
J.W. Bray Co.
Soddy Daisy, TN

Robert Brooks
Shaw Company
Dalton, GA

Coats & Clark
International Representatives

Herb Duncan
VWC
Atlanta, GA

Kesha Dupree
J.W. Bray Co.
Soddy Daisy, TN
Jim Gilmer  
Craftex, Inc.  
Latta, SC

Tom Heckman  
Department of Commerce

Harry Holding  
The Hartwell Co.  
Hartwell, GA

Jim Ivey  
Shaw Co.  
Dalton, GA

Randy Jay  
Atlanta Journal & Constitution

Dan Kazzez  
Paperfree  
Washington, DC

Ken Keene  
I.C. Isaacs & Co.  
Carthage, MS

Charles Marshall  
Marshall & Gross, Inc.  
Marietta, GA

Ray O'Connell  
O'Neill Developments  
Marietta, GA

Dick Plunkett  
Sewell Co.  
Bremen, GA

Warren Ragsdale  
Southern Bell  
Atlanta, GA

Harry Riehle  
Systecon  
Duluth, GA
Roy Simmons  
Charter  
Marietta, GA  

Terry Stein  
Carter & Associates  
Atlanta, GA  

Sandy Thompson  
North Metro Tech  
Acworth, GA  

Jeff Whalen  
Warren Featherbone  
Athens, GA  

Jay Whorton  
Marietta Daily  

Dick Yardley  
Kuris High Tech Systems  
Norcross, GA
SECTION III
<table>
<thead>
<tr>
<th>TASK ITEM</th>
<th>YEAR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quarter</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>DEMONSTRATION PLANT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Establishment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Demonstrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Major</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Minor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COALITION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Establishment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Operation &amp; Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TECHNOLOGY TRANSFER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- AMIS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Publicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECONOMICS ANALYSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADVISORY COMM. MEETINGS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REPORTING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Monthly (3 / quarter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Quarterly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Annually</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APPAREL ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION PROGRAM SCHEDULE

PERFORMANCE PERIOD 090189 - 093089
<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>MONTH</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE I FUNCTION ARCHITECTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review Industrial Practices</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Functional Architecture Specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Build Model and Document</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE II INFORMATION ARCHITECTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study Information in Industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Hierarchical Info. Flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Information Architecture Specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Build Model and Document</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE III DYNAMICS ARCHITECTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construct &quot;What If&quot; Scenarios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyze Information Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Dynamics Arch. and Simulate &amp; Doc. Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Generic Apparel Arch.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GENERIC ARCHITECTURE FOR APPAREL MANUFACTURING PROGRAM SCHEDULE**

**PERFORMANCE PERIOD** 090189 - 093089
<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MONTH</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE I</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review Past Research Efforts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop &amp; Refine Ind. Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collect Info. Through Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyze Results of Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE II</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Structured Rep. of Current Practice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Additional Factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interact Findings with Industry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Ranking Scheme</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE III</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation: Programming, Debugging, Manual Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Testing and Refinement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tech. Report and Installation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**KNOWLEDGE-BASED FRAMEWORK FOR TROUSER PROCUREMENT PROGRAM SCHEDULE**

**PERFORMANCE PERIOD 090189 - 093089**
### PHASE I

**Knowledge Base Development**
- Literature Review & Selection of Experts
- Economic Impact of defects
- Classification of defects
- Structuring of knowledge
- Establishing origins of defects
- Identifying remedies of defects
- Technical Report

### PHASE II

**Analysis & Software Development**
- Develop and mail questionnaire
- Analyze questionnaire responses
- Implement in software
- Industry-wide economic impact
- Develop software manual
- Debug/field-test software
- Gather data for other garments
- Technical Report

### PHASE III

**Refinement & Knowledge Base Extension**
- Complete software development
- Complete software manual
- Develop training program
- Complete extended defects
  - Knowledge base (other garments)
- Analyze Choice of methodology
- Final Report & Demonstrate Software Product

### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

PROGRAM SCHEDULE

**PERFORMANCE PERIOD** 090189 - 093089
## SHORT TERM TASK

### and SUBTASK ITEM

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
</table>

### Phase I:
- Data collection
- (demonstration mill)
- Model Development

### Phase II:
- GPSS coding of model
- Data collection for model
- Validation of model

### Phase III:
- Case studies for model verification
- Adoption to modular manufacturing
- Installation of the simulation
  of the AAMTD center
- Documentation of results

---

**DISCRETE EVENT SIMULATION PROGRAM SCHEDULE**

**PERFORMANCE PERIOD 090189 - 093089**
<table>
<thead>
<tr>
<th>ITEM</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature review &amp; site selection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthropometric data collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance measure development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase II:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan candidate interventions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field test interventions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase II report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase III:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop candidate approaches</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct tests at ANIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase III report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase IV:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify training objectives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify instructional approaches</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field test materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revise materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present training workshop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PRINCIPLES OF ERGONOMICS**

**PROGRAM SCHEDULE**

**PERFORMANCE PERIOD 090189 - 093089**
### IN PROCESS QUALITY CONTROL: SEWING DEFECTS
#### PROGRAM SCHEDULE

**PERFORMANCE PERIOD** 090189 - 093089
**IN PROCESS QUALITY CONTROL: FABRIC DEFECTS**

**PROGRAM SCHEDULE**

**PERFORMANCE PERIOD 090189 - 093089**
<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM</td>
<td>1  2  3</td>
</tr>
<tr>
<td>Study of Existing Systems</td>
<td></td>
</tr>
<tr>
<td>Contact Vendors</td>
<td></td>
</tr>
<tr>
<td>Study of Various Systems</td>
<td></td>
</tr>
<tr>
<td>User Site Visits</td>
<td></td>
</tr>
<tr>
<td>Technical Analysis</td>
<td></td>
</tr>
<tr>
<td>Literature Review</td>
<td></td>
</tr>
<tr>
<td>Analytical Study</td>
<td></td>
</tr>
<tr>
<td>Formulation of New Ideas</td>
<td></td>
</tr>
<tr>
<td>Technical Analysis</td>
<td></td>
</tr>
<tr>
<td>Cost Analysis</td>
<td></td>
</tr>
<tr>
<td>Cost Data Collection for Existing Systems</td>
<td></td>
</tr>
<tr>
<td>Cost Estimates for Proposed New Systems Analysis</td>
<td></td>
</tr>
<tr>
<td>Reporting</td>
<td></td>
</tr>
</tbody>
</table>

IMPROVED Marker Making Program Schedule

PERFORMANCE PERIOD 090189 - 093089
<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>Phase I</th>
<th>Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Month</td>
<td></td>
</tr>
<tr>
<td>Study Existing FWG's</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Visits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary of Findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study of Current Work Methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Visits</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Data Collection</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Analysis of FWG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature Review</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Modeling and Analysis</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Design of Methodology</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Experimentation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Summary of Results</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Development of VME</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specifications</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hardware Implementation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Software Implementation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Design Database</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Design and implement</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial Prototype</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Refinement and Expansion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Demonstration 1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Demonstration 2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Establish Experimental FWG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification of Workers</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Training</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Experimentation and Observation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Data Collection</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reporting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phase II</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Flexible Work Groups
Program Schedule
Exhibit 3.6

PERFORMANCE PERIOD 090189 - 093089
### Phase I:
- List programs & activities to be tracked
- Develop a computer based filing system
- Develop questionnaire to assess industry changes

### Phase II:
- Review existing tracking & enter into database
- Implement new tracking & enter into database
- Inform industry and AAMTD vendors about program
- Visit DLA contractor to gather cost data
- Distribute questionnaires

### Phase III:
- Evaluate questionnaire feedback
- Estimate cost savings on military garments
- Evaluate compiled data
- Prepare final report

---

**MEASURING AAMTD EFFECTIVENESS**

**PROGRAM SCHEDULE**

**PERFORMANCE PERIOD 090189 - 093089**
September Monthly Report

APPAREL MANUFACTURING TECHNOLOGY CENTER

Contract Number: DLA900-87-0018
Performance Period: 9/10/91 - 9/30/91

Sponsored by:

THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

Submitted by:

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology
and
Southern College of Technology

October 18, 1991
## Table of Contents

### Executive Summary

1

### Research Projects

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic Architecture for Apparel Manufacturing</td>
<td>6</td>
</tr>
<tr>
<td>Knowledge Based Framework For Trouser Procurement</td>
<td>8</td>
</tr>
<tr>
<td>Analysis of Defects in Trouser Manufacturing</td>
<td>10</td>
</tr>
<tr>
<td>Problem Solving for Apparel Manufacturers: Utilization of AMA</td>
<td>13</td>
</tr>
<tr>
<td>Ergonomic Principles</td>
<td>16</td>
</tr>
<tr>
<td>In-Process Quality Control: Fabric Defects</td>
<td>18</td>
</tr>
<tr>
<td>Flexible Work Groups</td>
<td>22</td>
</tr>
<tr>
<td>Problem Solving for Apparel Manufacturers: In-Plant Assistance</td>
<td>24</td>
</tr>
<tr>
<td>Location Technologies for Apparel Assembly</td>
<td>27</td>
</tr>
<tr>
<td>Nontraditional Economic Justification of Equipment</td>
<td>28</td>
</tr>
</tbody>
</table>

### Data Accession List

35

### Program Schedules

### Notes
Outreach and Industry Liaison

John Adams conducted an energy efficiency audit of Dowling Textile Company. The activity, involving two undergraduate students, identifies opportunities for the host company to achieve greater efficiency in utility costs.

Several manufacturers were contacted and invited to special demonstrations at the AMTC during the following months. Demonstrations will focus on the special interests of the guests plus overall manufacturing innovations related to BDU and similar apparel items.

On September 12, Carol Ring and Howard Pettigrew met with Scott Hall from Fame Products, Inc. Hall is investigating the advantages of the automated Reece Pocket Setter. Carol Ring stitched several samples on fabric furnished by Hall with the Reece Automatic Pocket Set Machine, Model 46. Advantages in method, quality and standard time were discussed. Pettigrew explained the mechanical adaptability of different clamps for several styles. Hall will present these samples and information obtained as part of his justification for purchasing the automated equipment.

Carol Ring and Howard Pettigrew met with Dan Dauby and Primo Quattrini of Private Line Group, Inc on September 17. Private Line is purchasing a CAD system for patterns and markers in the near future. Educational opportunities at Southern Tech involving CAD technology and other apparel equipment for (present and future) employees and future engineer resources were discussed at length. Several pieces of sewing equipment including the Rimoldi 406 Automatic Belt Loop and Union Special 2800 E-3 J-Stitch machine were demonstrated and discussed as possible investments for the Private Line bottom plant.

Dr. Jayaraman conducted several meetings with Dowling Textiles throughout September. On September 4, a written summary of the production process was given to Dowling and discussions on this topic were held. On September 10, Dowling detailed the purchasing process. On September 17, a written summary of the purchasing process was given to Dowling. Also, Dowling was given a time-task schedule of objectives and tasks which will serve as the roadmap for the project. Meetings were held with manufacturing personnel on September 17 and 20.

Dr. Wayne Tincher assisted in planning a tour of the vision research laboratory for the Burlington Industries Denim Division during the Bobbin Show. A letter of appreciation from Ms. Darlene Ball, Manager for Customer Support for the division and co-chairperson
of the Apparel Research Committee Subcommittee on Research Needs, is included in the Notes section.

Trade Shows and Meetings

AMTC presented a booth at the 1991 Bobbin Show. Traffic was excellent - Approximately 270 show attendees requested information at the booth. In addition, most AMTC personnel attended the Bobbin Show.

Highlights of the Bobbin Show this year included: voice activated motors; ergonomic work stations; integrated systems; computerized cutting machines for small manufacturing; pneumatic attachments for sewing machines; and advanced pattern development systems.

John Adams sat as a panelist at the Apparel Research Committee Seminar: "A technology Briefcase: Research & Development Around the World". The session received excellent presentations from Fred Golden of Fashion Institute of Technology; William Watkins of Veit, Inc.; Joe Off of Textile/Clothing Technology Center; and Paul Taylor of the University of Hull, UK. Dan Wright of Dowling Textiles voiced that the session was the best he attended at the show.

Larry Haddock and Bill Cameron attended the Apparel Education Foundation dinner in Atlanta on September 23. This year’s honoree was Mr. Lawrence R. Pugh, Chairman and Chief Executive Officer of VF Corporation. This dinner raised $150,000 to benefit students enrolled in an apparel curriculum including Southern Tech students.

Dr. Wayne Tincher attended the International Textile Machinery Association (ITMA) exposition in Hanover, Germany from September 24-27. This is the world’s largest exhibit of textile and related manufacturing equipment. In 1991, ITMA had 1,300 exhibitors from 35 countries and occupied over 2 million square meters of exhibit space. One small building was devoted to apparel manufacturing equipment, but this was not a major feature of the show.

In connection with Ergonomic Principles, Mike Kelly presented the poster show at the Human Factors Society annual meeting in San Francisco, CA.

John Bartholdi and Charlotte Jacobs-Blecha travelled to Cameron Station to discuss their pending proposal with Don O’Brien and Julie Tsao. Mr. Bartholdi presented the plans to implement the methodologies which result from this research project.

Pilot Plant Equipment and Systems

Gerber Garment Technology removed our computerized cutter and replaced it with a new
model.

At the Bobbin Show AMTC talked with various vendors regarding some special pieces of equipment that are still needed (on consignment) to enhance the high technology in the BDU manufacturing demonstration lab.

**Battle Dress Uniform Production Plans**

We continue to train operators one day per week and conduct demos at least one day per week. Generally, demonstrations are conducted on Thursdays. Each demonstration features the problems and interests of an invited apparel company. The demonstrations are also open to the public.

**Papers Published**

No papers were reported to be published during the month of September. However, several abstracts were in preparation for the coming Third Academic Apparel Research Conference to be held in February 1992. Also, industry interest has manifested in commercializing the results of the Sewing Defects project, if prototype testing is successful.

**Demonstrations and Tours during August, 1991**

In addition to our training activity and visiting the Bobbin Show, we were able to conduct several demonstrations during the month of September.

- **September 12**  
  Eight students from DeKalb Technical College came to the AMTC for a demonstration.

- **September 18**  
  Nineteen customers of IBM were here for a Plant Applications Sales Seminar and participated in a demonstration.

- **September 23**  
  Connie Pfeiffer and a party of six from Wright Patterson Air Force Base were provided a demonstration.

  Mr. James Della Polla and Colonel Bill Meadows from DPSC led a group of eight for a demonstration.

- **September 30**  
  Eight students from Berry College participated in a demonstration of the labs.
Activities Scheduled for Next Month

We have invited four different apparel manufacturing firms to come to AMTC during the month of October for special demonstrations. They have agreed to a meeting after the demonstration where we will discuss the trends of the industry and exchange of information. This is an effort to seek guidance from the people in the industry regarding directions we should take in order to provide a better service to the industry.

AMTC Proposals Submitted for Review

Design and Development of a Generic Architecture for Apparel Manufacturing: Support Other Groups That Need to Contribute or Use the Architecture (Maintenance of AMA) was submitted in September.

AMTC Projects Recently Funded

There were no new projects funded during September.

Ongoing Research

<table>
<thead>
<tr>
<th>Research Project</th>
<th>Principle Investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen. Architecture for Apparel Manufacturing</td>
<td>Sundaresan Jayaraman</td>
</tr>
<tr>
<td>Knowledge Based Framework</td>
<td>Sundaresan Jayaraman</td>
</tr>
<tr>
<td>Analysis of Defects Trouser Manufacturing</td>
<td>Sundaresan Jayaraman</td>
</tr>
<tr>
<td>Problem Solving for Apparel Manufacturers: Utilization of AMA</td>
<td>Sundaresan Jayaraman</td>
</tr>
<tr>
<td>Ergonomics</td>
<td>Dan Ortiz</td>
</tr>
<tr>
<td>Fabric Defects</td>
<td>Wayne Tincher</td>
</tr>
<tr>
<td>Flexible Work Groups</td>
<td>C. Jacobs-Blecha</td>
</tr>
<tr>
<td>Apparel Problem Solving</td>
<td>Susan Shows</td>
</tr>
<tr>
<td>Location Technologies</td>
<td>Wayne Tincher</td>
</tr>
</tbody>
</table>
Economic Justification of Equipment

Bill Riall

Detailed status reports follow.
Research Projects Detail
GENERIC ARCHITECTURE FOR APPAREL MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

To be successful, competitive and achieve excellence in manufacturing, the U.S. apparel industry must lead in successful use of the most advanced concepts and methods including Computer-Integrating Manufacturing (CIM). An important prerequisite for the successful implementation of CIM is an architecture of the apparel manufacturing enterprise. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to enhance the state-of-the-art in apparel manufacturing.

I.1 Introduction

The research work began in July 1988 and is being carried out in three phases. This report reviews the progress made during the month of September, 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Mr. Rajeev Malhotra, graduate student who completed his PhD in this area, was the Graduate Research Assistant.

I.3 Travel

No travel specifically for this project was conducted during September.
II. RESEARCH STATUS

II.1 Integrated Framework for Enterprise Modeling (IFEM)

Work has been continuing on the development of IFEM, a new approach to enterprise modeling that overcomes the shortcomings of the IDEF2 methodology and integrates the function, information and dynamics models of an enterprise into a single framework.

II.2 Final Report

Work on writing the Final Project Report is in progress.

II.3 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

III.1 Final Report

Work will continue on finishing the Final Project Report.
KNOWLEDGE BASED FRAMEWORK FOR TROUSER PROCUREMENT

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

The Department of Defense is the single largest consumer of apparel items in the free world procuring approximately $1.6 billion worth of apparel every year. The old practice of using sealed bid procedures and awarding contracts to the lowest bidder is giving way to Best Value Procurement. Such an informed and knowledge-based procurement approach would not only help the government but would also have an overall beneficial effect on the apparel industry. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to assist in the Best Value Procurement efforts.

I.1 Introduction

The research work began in July 1988 and is being carried out in three phases. This report reviews the progress made during the month of September, 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Howard Olson is the Research Investigator and Mr. Sambasivan Narayanan is the Graduate Research Assistant.

I.3 Travel

No travel specifically for this project was conducted during September.
II. RESEARCH STATUS

II.1 Software Delivery

BEST Forms and BEST Software have been ready for delivery to DLA. BEST runs on an MS-DOS machine with 2MB of extended memory and Nexpert Object (Run-time version). BEST Forms require the Quattro spreadsheet program. BEST Forms are also available as a WordPerfect file.

II.2 Apparel Industry Magazine Article on Research Endeavor

As a result of an article in the August 1991 issue of Apparel Industry Magazine, Ms. Kara Buttmer of Eagle’s Eye Company in Conshohocken, PA, requested additional information on the project. A copy of BEST Forms has been sent to Ms. Buttmer.

II.3 Final Report

Work is continuing on writing the final report on the project.

II.4 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

The specific plans for the coming month are outlined in this section.

III.1 Final Report

Work on the final project report will be continued.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

The production of high quality and defect-free apparel goods is a crucial necessity for combating imports from overseas apparel manufacturers. Products of superior quality not only fetch a premium price but also account for customer satisfaction and consistent consumer demand. Consequently, there is a need to examine ways of reducing defects and improving product quality. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to improve the quality of apparel products manufactured in the country.

I.1 Introduction

The research work began in December 1988 and is being carried out in three phases. This report reviews the progress made during the month of September 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Phiroze Dastoor is the Research Investigator, while Dr. Krishna Parachuru served as one until recently. Mr. K. Srinivasan has been the Graduate Research Assistant on the project.

I.3 Travel

No travel specifically for this project was conducted during September.
II. RESEARCH STATUS

II.1 Software Implementation of Sewing Defects (on UNIX)

The software implementation of SDAS on the UNIX operating system has been completed. However, addition of further details regarding packing and folding defects, as well as some trim defects may continue during the testing stage. The X11-based graphical user interface has been completed. Using this graphics front-end to SDAS allows several sessions of SDAS to be run on different networked machines, each communicating over TCP/IP with a common global Oracle database for the purpose of recording defect occurrences. This demonstrates a distributed processing capability, which is very important in actual shop-floor inspection.

II.2 Software Implementation of Sewing Defects (on DOS)

The porting of SDAS software to DOS is complete. The system has been tested, and the user interface is complete.

II.3 Database Integration with FDAS and SDAS Systems (on UNIX)

The SDAS software (written in Nexpert) has been fully integrated with the Oracle database system. The SDAS + Oracle development model takes advantage of the multi-user features of Oracle on a UNIX computer system, and is able to collect/transmit information from/to multiple sessions of the SDAS system.

Similarly, FDAS also uses the Oracle database system to keep track of the defect data it generates.

II.4 Database Integration with FDAS and SDAS Systems (on UNIX)

Nexpert Forms interfaces have been developed on the DOS platform, as visual front-ends for the two software systems. Both FDAS and SDAS now communicate with the Oracle DBMS for writing defect records, as already accomplished on the UNIX system. However, only single sessions of each system can interact with a single copy of Oracle running on the same DOS computer.

II.5 Writing of User Manuals

Both user manuals are 90% complete. They outline the different ways the user can use
FDAS and SDAS on the DOS platform but have yet to incorporate instructions regarding the recording of defects data into the Oracle database (since that work has just been finished for both FDAS and SDAS).

The systems share some commonality, in terms of modes of usage of their respective user interfaces and the protocols used to communicate with the database. However, their internal workings and structure are quite different, and the design and implementation information will be included in the project report and not in the user manual.

II.6 Original Research Task Schedule

A copy of the time-task schedule included in the original research proposal is attached.

III. PLANS FOR NEXT MONTH

III.1 Design and Implementation of SDAS (on UNIX and DOS)

Work on further additions to the SDAS knowledge base specifically dealing with trim defects (zippers, thread, buttons, etc.) as well as folding/finishing problems will be continued.

The software will also have references to some of the major fabric defects. However, this will be applicable only for defect tracking purposes, since detailed classification or analysis of fabric defects is taken care of by FDAS.

III.2 Writing of User's Manuals

The FDAS and SDAS user manuals have to be updated with information on using the Oracle database in tandem with the main FDAS/SDAS software, for recording defects data.

III.3 Writing of the Final Project Report

Work will continue on writing the Final Project Report.
I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

The basic objective of the research effort is to demonstrate the use of the apparel manufacturing architecture (AMA), developed on an earlier project, as a blueprint for implementing computer-integrated manufacturing systems in the apparel industry. This research project is funded by the U.S. Defense Logistics Agency (DLA) as part of its efforts to enhance the state-of-the-art in apparel manufacturing.

I.1 Introduction

The research work began in May 1991 and is being carried out in three phases. This report reviews the progress made during the month of September 1991. It also outlines the work to be carried out in the coming month. The report provides a means of comparing the actual progress achieved with the original time-task schedule identified in the initial project proposal.

I.2 Project Personnel

Dr. Sundaresan Jayaraman is the Principal Investigator. Dr. Rajeev Malhotra is the Research Investigator. Mr. K. Srinivasan, graduate student working on his Ph.D. in the area of CIM, is joining the effort as a Graduate Research Assistant.

I.3 Travel

Please see Dowling Textiles in Section II.1 below.
II. RESEARCH STATUS

II.1 Dowling Textiles

Meetings at Dowling Textiles have been continuing on a regular basis. At the meeting on September 4th, a written summary of the production planning process (based on the August 26th meeting) was given to Mr. Andrew Boyd and Ms. Ali Barr of Dowling. Additional discussions were held on the production planning process. On September 10th, Mr. John Hangar, the Dowling Vice President responsible for Fabric Purchasing, explained the purchasing process in detail. A written summary of the purchasing process was presented to Dowling on September 17th. On the same day, meetings were held with individuals responsible for trim procurement and marker making & cutting departments, to gain an understanding of the existing operations. Another meeting was held on September 20th with manufacturing personnel.

At the September 17th meeting, a time-task schedule outlining the objectives of the endeavor and the various tasks in the project was given to Mr. Boyd and Ms. Barr. The schedule was discussed and there was general consensus on the scope and plan of action. This document will serve as the roadmap for the duration of the project. In short, the progress on the project has been quite good and AS IS modeling will commence in the coming month.

II.2 Hewlett-Packard Manufacturing Management System

To integrate the production facilities available at AMTC, the HP Manufacturing Management II (MM II) software running on HP 3000 minicomputer at the center is being customized to conform to the AMA. MM II is a general-purpose manufacturing management package that consists of modules that handle various enterprise functions such as inventory control, manufacturing requirements planning, order entry, shopfloor control, purchasing, costing and general ledger. The MM II modules share the enterprise data which is maintained in the TurboIMAGE network database on the HP3000. The work currently in progress involves modifying the data definitions used by the MM II package to suit the specific needs of an apparel manufacturing enterprise. The MM II data definitions are being tailored to the specifications provided by the information model of AMA. The data entry screens and reports of MM II are also being customized for apparel manufacturing.

A report on the work carried out until now is being prepared for submission to HP.
III. PLANS FOR NEXT MONTH

III.1 Dowling Textiles

The interaction with Dowling Textiles will proceed on a regular basis. The AS IS modeling of Dowling's Production Planning process will be initiated.

III.2 Hewlett-Packard Manufacturing Management System

Continue documenting the work carried out on the system.
DESIGN & DEVELOPMENT OF A SELF-STUDY COURSE FOR APPAREL SUPERVISORS IN THE PRACTICAL APPLICATION OF ERGONOMIC PRINCIPLES

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

I.1 Introduction

The primary mission of this research task is the development of a self-study course in applied ergonomics for supervisors in the apparel manufacturing environment. The purpose of the effort is to create ergonomic awareness at the hands-on manufacturing level where physiological and psychological problems related to work station and equipment design are readily observed and corrected. Ergonomics can impact the workplace in the prevention of musculoskeletal disorders, the reduction of operator fatigue, and the improvement of operator adaptation to advanced manufacturing technology. Corresponding manufacturing concerns addressed include: production, training, attrition, absenteeism, and workforce availability.

The phases of the task leading up to the actual production of the course provide an assessment of ergonomic conditions in the conventional workplace, and an investigation of ergonomic concerns in advanced technology apparel manufacturing respectively. Each phase contributes to the information base for development of the course as well as providing valuable information (e.g. operator anthropometric data to the ergonomic research, equipment design, and apparel manufacturing communities).

I.2 Project Personnel

Dan Ortiz is the Project Director. Project support for Phase IV include: Nancy Davis, Research Associate II, Director Publications Branch; and Rae Adams, Research Associate I.

I.3 Travel

Mike Kelly travelled to San Francisco, CA to present the poster show at the Human Factors Society annual meeting.
II. RESEARCH STATUS

PHASE IV: DEVELOPMENT OF ERGONOMICS TRAINING MATERIALS

The manual and video entitled "A Stitch in Time: The Supervisor's Guide to Ergonomics" is now available to industry. Over 95 requests for the training package (i.e., tape and/or manual) have been received and processed in the month of August. Seventy-five requests were processed in the month of September. Over 400 manuals and 345 tapes have been mailed out to industries and institutions across the United States and Europe and Mexico.

A presentation of the Video and Manual was completed at the Bobbin Show. Also, a poster show describing our phase results and the purpose of the manual and video was presented at the Human Factors Society annual meeting in San Francisco, CA.

PHASE V: ERGONOMICS IN MODULAR MANUFACTURING

We are presently processing the data collected at Plants D and E. The carpal tunnel syndrome symptom survey (pain and numbness in the hands at night) revealed that Plant E (trouser manufacturing) had a substantially greater prevalence of individuals reporting the symptom (over 30 percent of interviewees) than Plant D (less than 10 percent). The plant E results parallel the results obtained at two trouser plants in the Phase I study (more than thirty percent also reported the symptom). Although only preliminary this finding suggests that between station movement may not have a positive effect on the prevalence of this CTS symptom among sewing operators. Many of the jobs in the Plant E modules require similar hand postures (predominantly flat press and pinch grip) and levels of repetition. Consequently, the only relief from the risk factors associated with cumulative trauma disorders appears to be during the walk between workstations. These findings will be explored further as data analysis progresses toward completion.

III. PLANS FOR NEXT MONTH

A return trip to Plant D to complete the workstation measures and collect additional comfort data from standing workers will be made in October.

The "Stitch in Time" video will be shown at a Clemson Apparel Ergonomics Seminar
IN-PROCESS QUALITY CONTROL: FABRIC DEFECTS

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER

I.1 Introduction

The DLA project on In-Process Quality Control: Automatic Detection of Fabric Defects has completed its thirtieth month of program work. The project technical management is under the direction of Wayne C. Tincher, the project Principal Investigator, and the administrative management is under the supervision of John Adams, the AMTC program manager.

I.2 Project Personnel

Wayne C. Tincher has responsibility for the overall design of the cut part inspection workstation and is directing the work on color measurement of cut parts and the criteria for color acceptability for parts that can be sewn together. He is being assisted on the project by Mr. Amit Kumar, graduate student in the School of Textile and Fiber Engineering. The development of the machine vision systems for cut part inspection is under the direction of Mr. Wayne Daley, Research Engineer in the Georgia Tech Research Institute. Mr. Daley is being assisted by Richard Carey, research Engineer, Marlon Moses, an Electronics Technician and Frank Schrorer a Student Assistant. Mr. Wiley Holcomb has responsibility for developing the transport system for the cut parts, designing the take-off device, and overall integration of the components for the cut-part inspection demonstration unit.

I.3 Travel

There was no project related travel during this month.
II. RESEARCH STATUS

II.1 Survey Existing Technology
No work was undertaken on this phase of the project during the month.

II.2 Identify and Define Defects
Work on this phase of the project is essentially complete.

II.3 Lighting and Optics Design
Work on this phase of the project is essentially complete.

II.4 Test Design Concepts
Work on this phase of the project is essentially complete.

II.5 Develop Machine Vision Algorithms
No work was undertaken on this phase of the project in September.

II.6 Develop Color Analysis System
This phase of the project is essentially complete.

II.7 Construction of Proof-of-Concept Workstation
Virtually all of the activity this past month has been directed toward assembly of the proof-of-concept cut-part inspection workstation.

All of the major equipment items are now on order or on hand. We currently have on hand the area vision system and personal computer; the color measurement system and personal computer; the loader the programmable logic controller; and the servo drive for the conveyor. The conveyor is scheduled to ship on October 25.

An EG&C Reticon line camera system has been selected for the proto-type unit and orders
have been placed for this last component.

Detailed design work is continuing on the components that are being fabricated at Georgia Tech, including the instrument stand, the unloader, and the pallet mechanism. A line drawing showing the placement of the various units is given in the attached figure. The dotted lines in the central portion of the lower drawing indicate the positions of the area camera, line camera and color measurement system with the appropriate loading and unloading areas of the belt to the left and right. Construction of the frame and instrument mounting systems has begun.

III. PLANS FOR NEXT MONTH

Major effort during the remainder of the project will continue to be devoted to the procurement of parts and construction of the prototype workstation.
Conveyor, Instrument stand, and Loader

Planview of Conveyor, Instrument stand, and Loader

FIGURE
APPLICABILITY OF FLEXIBLE WORK GROUP METHODS TO THE MANUFACTURE OF MILITARY UTILITY TROUSERS

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

I.1 Introduction

The DLA project on Flexible Work Groups (FWG) has completed its twenty-fifth month of program work. The technical and administrative project management is under the supervision of Dr. Charlotte Jacobs-Blecha, the Project Director. This monthly report is composed of the summary and technical reports submitted by the Project Director and members of the project team, and reviews the month's technical progress as proposed in the Program Schedule.

I.2 Project Personnel

In addition to the Project Director, other personnel working on the project are as follows. From EDL are Richard Carey, research engineer and graduate student Steve Nichols. From the School of Industrial and Systems Engineering (ISyE) are Dr. H. Donald Ratliff, Regent's Professor; Dr. John Bartholdi, Associate Professor; and Ph.D. student, Don Eisenstein.

I.3 Travel

Travel was made this month by John Bartholdi and Charlotte Jacobs-Blecha to Cameron Station to discuss with Don O'Brien and Julie Tsao our pending proposal. The proposal has been accepted subject to two requested modifications regarding implementation. These issues have been addressed by the project team and an associated apparel company. A presentation was made by John which explained what we have planned to do to implement the methodologies resulting from this research project. Don O'Brien agreed to immediately provide a funding extension for six months, allowing time for the modified proposal to be submitted, reviewed, and approved.
II. RESEARCH STATUS

II.1 Analysis of FWG

We have continued to study the coordination of workers in a flexible work group.

1. Decentralized Control of Workers

We continue to investigate the decentralized coordination of workers on a manufacturing line such as the TSS (Toyota Sewing System). We have previously discussed the uniform processor model where the difference in speed between workers is uniform over each task. We have shown that if one orders the workers on the line from slowest to fastest that the system converges to a stable configuration that attains the largest possible production rate. This convergence has been proven for only systems in which workers never need wait for a machine. However, our simulation has provided experimental evidence that such a line converges whether or not there is a "bottleneck" task. If such behavior can be proved to occur for all such lines, this would mean that the line is stable and a high throughput is achieved even when the line is overstaffed or the speed of workers increases unexpectedly. To fully understand these lines we need a better understanding of when bottlenecks occur in such systems. With workers of different speeds a given task may be a bottleneck if operated by a slow worker, yet will not be a bottleneck if operated by a faster worker. We have some loose or sufficient conditions under which a task is a bottleneck, but we hope to find some tighter or necessary conditions for a task to be a bottleneck.

2. Graphical Simulation Model

The simulation model continues to provide insight and experimental evidence for the behavior of the TSS line. This month in particular, through our latest enhancements to the model, we were able to observe the convergence of the uniform processor model in the presence of a bottleneck machine. This effort will continue as we further examine bottlenecks in the uniform processor model.

3. Documentation and presentations

We continue to document our results in a formal report. In particular we continue our documentation of the uniform processor model.

II.2 Development of VME

Work continues on the VME to close the connections between the user interface and the algorithms produced by the research on modular manufacturing. This task is nearing completion.
PROBLEM SOLVING FOR APPAREL MANUFACTURERS:
IN-PLANT ASSISTANCE

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

Since January 1990, the Problem Solving for Apparel Manufacturers project has assisted manufacturers in solving problems by applying advanced manufacturing technologies, productivity engineering, and innovative management practices. AMTC is supporting DLA's goal to strengthen the domestic apparel industry by helping individual companies improve their manufacturing capabilities.

I.1 Introduction

This report covers progress made during September, 1991 and outlines tasks to be accomplished during the coming months. It provides a means of comparing actual progress achieved with the original time-task schedule identified in the project proposal.

I.2 Project Personnel

Gerry Doubleday and Susan Shows are co-directors of the project. Other AMTC personnel are participating as necessary on specific assignments.

I.3 Travel

September travel included visits to company sites to conduct implementation tasks and to meet with management to discuss implementation projects.
II. PROJECT STATUS

Ten diagnostic projects have been completed, with an eleventh project underway. Three implementation projects are on-going.

The project directors met with two Georgia Tech staff members who are interested in working on the project. Paolo Chiappina, an industrial engineer in the Augusta regional office, has a background in apparel manufacturing. Frank Mewborn works in the Madison regional office and was previously assigned to the Trade Adjustment Assistance Center. Both Paolo and Frank have conducted numerous projects in apparel plants and will work with Gerry and Susan to identify potential contractors and conduct analysis projects.

Independent consultants working with AMTC were contacted in September and advised about the new funding for the problem solving project. They will assist in locating potential contractors.

II.1 Diagnostic Projects

**Moka Shoes - boot manufacturer.** The diagnostic analysis for this government contractor was completed in September. Gerry Doubleday will meet with company management next week to discuss scheduling for the 30 man-day implementation project which will include:

1) revision of the incentive system
2) training for (2) industrial engineering technicians
3) training for IEs and supervisors in performance management techniques

**Wellco Shoes - boot manufacturer.** Moka Shoes is a wholly owned subsidiary of Wellco. AMTC will meet with management in October to discuss the possibility of conducting a diagnostic project for Wellco's North Carolina plant.

II.2 Implementation Projects

Implementation projects currently underway:

**L.A.T. Sportswear - tee shirt manufacturer.** Project has been underway since May to assist this firm in a plant expansion effort. AMTC audited equipment and rates, and made recommendations about building construction, layout, and equipment selection for the new facility.

Preliminary drawings and specs were presented to company management in September. Plant layout and staffing requirements were developed, along with a blueprint of the proposed building. Recommendations to invest in automated pattern making and cutting
equipment were also presented. The company president is currently reviewing the proposal.

*Kym Company - trouser manufacturer.* Implementation is nearing completion. One additional session of supervisory training is planned at the company's request.

The company's president is still interested in implementing a group incentive system, but has other problems to address at present. Gerry Doubleday and Susan Shows will meet with him at his earliest convenience to discuss project costs and funding alternatives.

The company has been receiving bidding information for government contracts. However, management advises that recent requests for bid have not matched their capabilities.

*U.S. Textiles - sweatshirt manufacturer.* AMTC made a proposal to provide further assistance to the company in its efforts to secure government bids. Management has not responded to the proposal.

Other implementation projects scheduled to begin:

*Maid Bess - uniform manufacturer.* interested in installing modular work groups.

*Elder Hosiery - hosiery manufacturer.* wants to implement a formal product costing system. Proposal sent to company management in September.

II.3 **Marketing Efforts**

Marketing activities which have been on hold will begin in October.

III. **PLANS FOR NEXT MONTH**

Continue with diagnostic and implementation projects.

Begin outreach efforts to identify new clients.
LOCATION TECHNOLOGIES FOR APPAREL ASSEMBLY

I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

The work on this project has been completed and the final report has been submitted.

A follow-on proposal is in preparation involving application of the results of this study in development of two low-cost vision technologies for application in apparel manufacturing.
I. MONTHLY PROJECT REVIEW FOR SEPTEMBER, 1991

I.1 Introduction

The DLA project continuing work on nontraditional economic justification methods for equipment purchases has completed its eighteenth month. The technical and administrative project management is under the supervision of Dr. B. William Riall. The objective of this project is to provide decision-makers in the apparel industry with software and training to improve the quality of the assessments made on equipment considered for purchase. Previous research has indicated that many of the benefits important to the health of apparel firms are not presently included in such assessments, thus biasing the decision against investment. This monthly report describes the progress made on each of the tasks scheduled for this month.

I.2 Project Personnel

Personnel who have worked on the project include Dr. Bill Riall, Mr. Robert Lann, and graduate student assistant Bill Shamblin. Dr. Riall was responsible for project management and the development of the specifications for the software. Mr. Lann is responsible for developing the software and Mr. Shamblin is responsible for data collection.

I.3 Travel

No travel was conducted in this reporting period.
II. RESEARCH STATUS

II.1 Task I - Equipment Review and Classification

Equipment has been classified into 9 categories according to their function within the apparel plant. The software under development will provide the user with guidance in applying the software to each of these categories as a first step towards economic analysis.

- Design
- Marker making
- Spreading
- Cutting
- Assembly
- Finishing
- Warehousing
- Materials handling
- Production Management

II.2 Task II - Development of Economic Performance Characteristics of Equipment

Discussions with equipment manufacturers and other knowledgeable persons have resulted in reasonably clear pictures of the interactions among most of the various functions performed by apparel equipment. The extent of these interactions is less than originally anticipated. Yet to be analyzed are modular systems and production management. These represent two extremely complex situations best evaluated after the basic structure of the software is established. Additional effort is now being devoted to specifying the algorithms and data sources that can be used in the quantification of each of these parameters. Qualitative factors are being developed separately.

II.3 Task III - Development of Preliminary Evaluation Criteria

Efforts have been concentrated on quantitative evaluations using traditional yardsticks (NPV, etc.) applied to items not traditionally quantified. The expansion of the scope of parameters subjected to quantification is seen as the first step towards a nontraditional approach. Where quantification is not possible, alternative structures for decision-making will be provided. It appears now that this nontraditional structure will consist of a weighted scoring system. The method used to input data into the scoring system will use some of the concepts of the analytical hierarchy process (AHP), rather than use a complete AHP approach. This is because of the complexity and the level of difficulty in interpreting the
results is greater for AHP than the typical executive is willing to support.

An additional task has been identified to assist in the evaluation. Often the greatest benefits are in the area of new markets made possible by the capabilities of new technologies. Assessing the value of these benefits requires an examination of the markets either quantitatively or qualitatively. The new task is the development a framework in which the market potential assessment can be made. This assessment would then be incorporated into the strategic planning components of the weighted scoring system.

II.4 Task IV - Software Development

The structure for the software has been established and is following the format common to many of the most widely used software packages available commercially today, and expected to be available in the future. This format was first used by Lotus and continues greatly enhanced with Excel and Windows. It uses a menu bar at the top of the screen with each menu choice representing another submenu or action which is displayed in the area beneath the menu bar. This structure has the advantage of allowing the user access to the full range of actions available without moving through lengthy tree structures.

The primary elements of the menu bar and their functions are:

Help: Provides general help on how to move through the menu system.
Profile: Allows the user to enter the data which will be used by all analyses. These data would include, for example, the fringe benefits rates to be applied to labor costs, the discount rate used in the NPV calculation, and the tax rates.
Data: First asks whether the user is working with an existing project, or a new project. A new project is given a name and a description can be provided. The user is then given the option of providing either investment data, operating data, or reviewing a summary of the data already entered. Investment costs are further subdivided into equipment purchases and project implementation costs. Further subdivisions are provided to assist the user in identifying the cost items which may be applicable. Three of the areas often left out of analyses for which methods of estimation are included in the software are turnover costs (i.e., the benefits of deskilling), inventory costs, and project introduction costs.
Analysis: The user is asked whether a Financial or Project Scoring analysis is desired. If Financial analysis is chosen, a structure is provided in which scenarios are compared and risk is assessed. The project scoring alternative includes ten categories each of which is weighted for importance by the user followed a scoring of each of up to five projects chosen for the analysis.
Reporting: Allows the user to print either the input data or the analysis results.
Files: Provides the user with file listing, renaming, and deletion capabilities.
A major revision to the planned structure of the software has taken place. The cost categories for the various equipment types has resulted in a comprehensive list applicable across all equipment types. It was apparent that a tradeoff existed between how fast the software would work, how complex it was to learn and use, and how specific the cost categories were to each equipment type. If, as originally planned, a different set of data input and analysis screens were to be used for each of the nine equipment types identified, then the software would require extensive use of overlays because of the 640K RAM limitation in effect for all DOS machines. These overlays reduce the speed at which the software is operated. Also, when the costs categories are different for each equipment type, the task of learning to use the software is greatly increased. The benefits of tailoring nine sub-categories of cost data would be a function of how different the approach would be from one equipment type to another. The analysis has shown a considerable congruence among equipment types. It was therefore decided that equipment specificity in the help screens available to the user would capture virtually all of the benefits of a more complex system with a considerable savings in speed and usability.

The software is currently being written in Pascal. A new version of Pascal, with additional features and greater efficiency, has been adopted for the project.

An extensive series of help messages are being developed that can be accessed by highlighting the element of the software of interest at any point in the analysis. Output formats have been developed for all but the revenue impact and scoring system reports.

II.5 Task V - Training Program Development

A preliminary structure for the training has been developed. It is anticipated that the training will require three days of intensive work with class sizes limited to 12-15 persons. The class will be divided in 3-5 teams each having responsibility to analyze a situation and report their results to the class for discussion. An approach investigated was to compose the teams of three persons from the same company representing the perspectives of production, marketing, and finance. Feedback from the apparel companies contacted has revealed that it is not feasible to expect three persons to be able to attend the training from a single company. It does appear feasible, however, to structure the cases used in the analyses so that one of the team members represents production interests and has the production data, one the financial, and one the marketing. The course agenda is tentatively established to be:

Day 1

Introduction and Plan for the course
What do we want to accomplish here?
How will we go about doing this?
What will be expected of you?
What can you expect of me?

Introduction to Net Present Value
- The irrefutable logic of NPV:
- Why money received next year is not the same as money received today. How can they be made comparable? (Check textbooks for presentations & exercises/demonstrations)
- Why is NPV such a good decision rule?
- Why is NPV not the best decision rule?

- Exercise 1: calculating a simple NPV

The limitations of NPV: components of a quality decision
- The forecasting nature of the decision process
- Looking into the future: dealing with uncertainty
- Assessing risk
- Conducting sensitivity analysis
- Intangibles
- The discount rate question
- With vs Without: the two basic alternatives common to all investment decisions

- Exercise 2: Applying the logic to With vs Without to calculate a NPV
  Incorporating different perspectives

Comprehensive Decision-Making
- The role of quantitative analysis
- The role of qualitative analysis

Lunch

Introduction to COMPASS: Getting started

Investment Costs
Purchases: Equipment
           Inventories
           Software
Implementation: Project Introduction
              Training
              Facilities
              Integration
              Set-up & Debugging

Operating Costs
Labor: Direct
       Indirect
       Turnover
Other Items: Fabric
External
Quality
Supplies
Interaction
Floor Space

Revenue Summary

Presenting an Example: Improving sewing productivity

How to use the documentation
- Exercise: Finding your way with Compass

Overnight Assignments (Read 1st case)

Adjourn

Day 2

Discuss case situation: Assessing a more automated marker-making system
Break into groups & Conduct analysis
Present results

Discussion; Critique

Lunch

Present Case 2: Assessing modular manufacturing units
Break into groups & Conduct analysis
Present results

Discussion; Critique

Distribute and Introduce Case 3

Adjourn

Day 3

Discuss case 3 situation: Variations on the other cases used to hone analysis & presentation skills.
Break into groups & Conduct analysis
Present results

Discussion; Critique

Wrap-up & Summarize

Complete Evaluation forms & Adjourn

The review of additional software options, as discussed in section II.4 has delayed the schedule for the training. It is now anticipated that the training will be conducted in March-April. Investigations with industry officials have indicated that a Spring presentation would be more convenient for their participation.

III. PLANS FOR NEXT MONTH

The revenue analysis component will receive attention in the coming month and help-screen texts are anticipated to be completed next month but not integrated into the software until the following month.
Data Accession List

APPAREL MANUFACTURING TECHNOLOGY CENTER

Contract Number: DLA900-87-0018
Performance Period: 910901 - 910930

Sponsored by:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

Submitted by:

Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology
and
Southern College of Technology

October 18, 1991
Date of visit: 9/11/91
Scott Hall
Plant Manager
Fame Products
Jaspar, GA

Date of visit: 9/12/91
Sherry Bryant
Assistant Professor
DeKalb Tech
8 Students

Date of visit: 9/17/91
Mr. Dan Dauby
Plant Manager
Private Line Group, Inc.
P.O. Box 580
Bowman, GA 30624

Date of visit: 9/17/91
Mr. Primo Quattrini
Vice President of Mfg.
Private Line Group, Inc.
IH 100 North
Franklin, GA 30271

Date of visit: 9/17/91
Mr. John M. Redman
Senior Economist
U.S. Department of Agriculture
1301 New York Avenue, NW
Washington, DC 20005

Date of visit: 9/17/91
Mr. Chuck Mague
IBM

Date of visit: 9/18/91
Margie Dixon
Project Leader
SIEMENS
3333 State Bridge Rd.
Alpharetta, GA 30202
Date of visit: 9/18/91
Mr. Bob Asseedi
IBM Tower
Atlanta, GA

Date of visit: 9/18/91
Mr. Roy Hopper
Marketing Representative
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Anne Amithge
Marketing Representative
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Daphene Jones
SEM
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Mr. James Bon
SEM
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Rochell McLain
SE
IBM
1201 W. Peachtree St.
Atlanta, GA
Date of visit: 9/18/91
Mr. Charlie Parsons
IS
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Lek Torrence
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Mr. Barry Balint
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Pamela Moys
IBM
1201 W. Peachtree St.
Atlanta, GA

Date of visit: 9/18/91
Diane Hartness
Marketing Representative
IBM
Albany, GA

Date of visit: 9/18/91
Buzzy Stevens
Marketing Representative
IBM
Albany, GA

Date of visit: 9/18/91
Harris Warsaw
IBM
Albany, GA
Date of visit: 9/18/91
Cathy LeMan
Marketing Representative
IBM

Date of visit: 9/18/91
Randy Wilson
Analyst
GoldKist
244 Perimeter Center
Atlanta, GA

Date of visit: 9/23/91
Major Daniel Starford
Operations Officer
U.S. Army - DPSC - VO
2800 S. 20th Street
Philadelphia, PA 19101

Date of visit: 9/23/91
Scott Golthoraite
Industrial Specialist
DPSC - V
2800 S. 20th Street Bldg. 13
Philadelphia, PA 19101

Date of visit: 9/23/91
Ardena Jarrells
Sample Maker
USAF
WPAFB
Dayton, OH 45433

Date of visit: 9/23/91
Maria Mavrouleas
Pattern Designer
USAF
WPAFB
Dayton, OH 45433
Date of visit: 9/23/91
Ana Haug
Sample Maker
USAF
WPAFB
Dayton, OH 45433

Date of visit: 9/23/91
David Lanthorn
A.F. Clothing B

Date of visit: 9/23/91
Connie Pfeiffer
Clothing Pattern Designer
USAF

Date of visit: 9/23/91
Dimitrios G. Lookoumidis
USAF Clothing

Date of visit: 9/23/91
John Yourk
Directorate of Manufacturing
Defense Personnel Support Center
2800 South 20th Street
Philadelphia, PA 19145

Date of visit: 9/23/91
Frank John Viola, Jr.
Directorate of Manufacturing
Defense Personnel Support Center
2800 South 20th Street
Philadelphia, PA 19145

Date of visit: 9/23/91
Fred Taylor, VME
Director of Manufacturing
Defense Personnel Support Center
2800 South 20th Street
Philadelphia, PA 19101
Date of visit: 9/23/91
Joseph V. D'Adamo
Industrial Specialist
Defense Personnel Support Center
2800 South 20th Street
Philadelphia, PA 19101

Date of visit: 9/23/91
James Della Polla
Chief, Mgt. Engineering
Defense Personnel Support Center
2800 South 20th Street
Philadelphia, PA 19101

Date of visit: 9/26/91
Bev Dinham-Smith
Director
HEART INTA
Kingston, Jamaica

Date of visit: 9/26/91
Paulette A. Rhode
Director/Export
Crimson Dawn Mfg.
2 Central Avenue
Swallowfield 5
Kingston, Jamaica

Date of visit: 9/26/91
Mabel Codling
Senior Instructor
James HEART Academy
76 Marcus Yancey Dr.
Kingston 13, Jamaica

Date of visit: 9/26/91
Gloria Russell
Consultant/Pattern Maker
HEART
Kingston, Jamaica
Date of visit: 9/26/91
Paul Herdsman
Program Manager
HEART
Kingston, Jamaica

Date of visit: 9/27/91
German Estefan
Senior General Manager
Carvajal S.A.
P.O. Box 46
Cali-Colombia, SA

Date of visit: 9/27/91
Jorge H. Bojanini
Q.C. Manager
Carvajal S.A.
P.O. Box 46
Cali-Colombia, SA
VISITORS TO AMTC
9/30/91

Elizabeth Watts, M.S., CHE, IDEC
Assistant Professor
Berry College
5011 Mount Berry Station
Rome, GA 30149

STUDENTS

Kristina Strayton
Stacey Powers
Cathy Watkins
Tracy Jinks
Amy Summerlin
Kim Crane
Karen Hays
Program Schedules

APPAREL MANUFACTURING TECHNOLOGY CENTER

Contract Number: DLA900-87-0018
Performance Period: 910901 - 910930

Sponsored by:
THE UNITED STATES DEPARTMENT OF DEFENSE
DEFENSE LOGISTICS AGENCY

Submitted by:
Economic Development Laboratory
Georgia Tech Research Institute
Georgia Institute of Technology
and
Southern College of Technology

October 18, 1991
### APPAREL ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION PROGRAM SCHEDULE

**PERIOD ENDING 9-30-91**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>TASK</th>
<th>YEAR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Quarter</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEMONSTRATION PLANT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Establishment</td>
<td></td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Demonstrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COALITION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Establishment</td>
<td></td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Operation &amp; Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TECHNOLOGY TRANSFER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- AMIS</td>
<td></td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Publicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ECONOMICS ANALYSES</td>
<td></td>
<td></td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ADVISORY COMM. MEETINGS</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>REPORTING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Monthly (3/quarter)</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>- Quarterly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Annually</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:● Indicates the completion of the task.
<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>MONTH</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 2 3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>PHASE I FUNCTION ARCHITECTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review Industrial Practice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Functional Architecture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Build Model and Document</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE II INFORMATION ARCHITECTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study Information in Industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Hierarchical Information Flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Information Architecture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Build Model and Document</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE III DYNAMICS ARCHITECTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construct &quot;Whol II&quot; Scenarios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyze Information Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Dynamics Architecture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and Simulate &amp; Document Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Generic Apparel Architecture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# KNOWLEDGE BASED FRAMEWORK FOR TROUSER PROCUREMENT PROGRAM SCHEDULE

**PERIOD ENDING 9-30-91**

<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>MONTH</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review Past Research Efforts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop &amp; Refine Industry Questionnaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collect Info. Through Questionnaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyze Results of Questionnaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Structured Report of Current Practice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Additional Factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interact Findings with Industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Ranking Scheme</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE III</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation, Programming, Debugging, Manual Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Testing and Refinement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report and Installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING PROGRAM SCHEDULE

**PERIOD ENDING 9-30-91**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
</table>

#### PHASE I
**KNOWLEDGE BASE DEVELOPMENT**
- Literature Review & Selection of Experts
- Economic Impact of Defects
- Classification of Defects
- Structuring of Knowledge
- Establishing Origins of Defects
- Identifying remedies of Defects
- Technical Report

#### PHASE II
**ANALYSIS & SOFTWARE DEVELOPMENT**
- Develop and Mail Questionnaire
- Analyze Questionnaire Responses
- Implement Software
- Industry-wide Economic Impact
- Develop Software Manual
- Setup/Field-test Software
- Gather Data for Other Garments
- Technical Report

#### PHASE III
**REFINEMENT & KNOWLEDGE BASE EXTENSION**
- Complete Software Development
- Complete Software Manual
- Develop Training Program
- Complete Extended Defects Knowledge Base (Other Garments)
- Analyze Choice of Methodology
- Final Report & Demonstrate Software Product
## PROBLEM SOLVING FOR APPAREL MANUFACTURERS: UTILIZATION OF AMA PROGRAM SCHEDULE

**Exhibit 3.6A**

**PERIOD ENDING 9-30-91**

| SHORT TERM TASK and SUBTASK ITEM | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|    |
| **PHASE I: SELECTION**          |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Establish Eligibility Requirement | ●●● |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Develop/Distribute Literature/   | ●●● | ●●● |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Announcement                     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Review Response                  |   |   |   |   |   | ●●● | ●●● | ●●● |   |    |    |    |    |    |    |    |    |    |    |
| Interact with Candidates         |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Present List to DLA             |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| **PHASE II: ANALYSIS**           |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Establish Problem/Task           |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Train/Educate in AMA             |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Analysis and Modeling            |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| **PHASE III: EVALUATION**        |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Review Solution                  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Cost/Benefit Analysis            |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Prepare for Workshop/Seminar     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Final Report                     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |

**Legend:**
- ●●●: High priority
- ●●: Medium priority
- ●: Low priority
- ○: No activity scheduled
# PRINCIPLES OF ERGONOMICS PROGRAM SCHEDULE

PERIOD ENDING 9-30-91

<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>MONTH</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature Review &amp; Site Selection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance Measure Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan Candidate Interventions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hold Test Interventions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase II Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE III</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Candidate Approaches</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct Tests of AMTC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase III Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE IV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify Training Objectives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify Instructional Approaches</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hold Test Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revise Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present Training Workshop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PHASE I**
- Literature Review & Site Selection
- Task Analysis
- Analysis
- Data Collection
- Performance Measure Development
- Phase I Report

**PHASE II**
- Task Analysis
- Plan Candidate Interventions
- Hold Test Interventions
- Phase II Report

**PHASE III**
- Develop Candidate Approaches
- Conduct Tests of AMTC
- Phase III Report

**PHASE IV**
- Identify Training Objectives
- Identify Instructional Approaches
- Prepare Materials
- Hold Test Materials
- Revise Materials
- Present Training Workshop
- Final Report
## IN-PROCESS QUALITY CONTROL: FABRIC DEFECTS PROGRAM SCHEDULE

**PERIOD ENDING 9-30-91**

<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>YEAR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey Existing Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify &amp; Define Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defect Optical Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting &amp; Optics Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Design Concepts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Machine Vision Algorithms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Color Analysis System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Conceptual Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design &amp; Construct Modules</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Modules</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHASE III</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire Components</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assemble Inspection System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test and Demonstrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Flexible Work Groups Program Schedule

**Period Ending 9-30-91**

<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>MONTH</th>
<th>PHASE I</th>
<th>PHASE II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study Existing FWG's</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature Review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Visits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary of Findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Study of Current Work Methods</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Visits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Collection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Analysis of FWG</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature Review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modeling and Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design of Methodology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary of Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Development of VME</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specifications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware Implementation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software Implementation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Database</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design and Implement Initial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prototype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstration 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinement and Expansion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstration 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Establish Experimental FWG</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification of Workers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimentation and Observation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Collection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reporting</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase II</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## APPAREL PROBLEM SOLVING PROGRAM SCHEDULE

**Exhibit 3.7A**

**PERIOD ENDING 9-30-91**

<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
<th>MONTH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establish Eligibility Requirement</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Develop Target Marketing List</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Develop Promotional Literature</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Distribute Literature</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Formulate Analysis Methodologies</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Telephone Interviews with Potential Clients</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td><strong>PHASE II</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visit Potential Clients</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Conduct Analysis for Selected Firms</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td><strong>PHASE III</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finalize Implementation Packages</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Begin Implementation of Companies with</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Completed Analysis</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Continue Additional Analysis / Implementation Projects</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
LOCATION TECHNOLOGIES FOR APPAREL ASSEMBLY PROGRAM SCHEDULE
Exhibit 4.0 A

PERIOD ENDING 9-30-91

<table>
<thead>
<tr>
<th>SHORT TERM TASK and SUBTASK ITEM</th>
<th>MONTHS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8</td>
</tr>
<tr>
<td>Selection of Garments</td>
<td></td>
</tr>
<tr>
<td>Establish Manufacturing Requirements</td>
<td></td>
</tr>
<tr>
<td>Review Current Methods</td>
<td></td>
</tr>
<tr>
<td>Review Available Location Technologies</td>
<td></td>
</tr>
<tr>
<td>Identify Most Useful Technology</td>
<td></td>
</tr>
<tr>
<td>Prepare Final Report</td>
<td></td>
</tr>
</tbody>
</table>
Notes
Dr. Wayne Daley  
Georgia Institute of Technology  
School of Textile and Fiber Engineering  
Atlanta, GA 30332

Dear Wayne:

Many thanks for spending time with us last Thursday to describe your work on Vision Inspection. We appreciate Dr. Tincher making the arrangements.

We are very interested in following the progress of this work and would like to visit Southern Tech when the module is complete and installed there.

The work you have done is a giant step forward in this arena and we hope it will lead to a full width fabric inspection system in the future.

If we can be of any assistance in your efforts please contact me.

Sincerely,

Warlene Ball, Manager  
Customer Support

DLB/wb

cc: Dr. Wayne Tincher - Georgia Institute of Technology  
Mr. Bill Hunter - Burlington Industries/Mooresville, NC  
Mr. Van Knox - Burlington Industries/Mooresville, NC  
Mr. Pryor Millner - Burlington Industries/Mooresville, NC  
Mr. Nathan Sandefur - Burlington Industries/Mooresville, NC  
Mr. Jim Slagle - Burlington Industries/Mooresville, NC
APPAREL ADVANCED MANUFACTURING TECHNOLOGY
DEMONSTRATION

SHORT TERM TASK
AMENDED FINAL TECHNICAL REPORT
PHASES I, II & III

In-Process Quality Control In Apparel Production:
Sewing Defects

to

DEFENSE LOGISTICS AGENCY

Short Term Task Under CLIN 0007 of
Contract: DLA 9000-87-D-0018

by

Georgia Institute of Technology
School of Textile & Fiber Engineering

October 1991
In-Process Quality Control In Apparel Production: Sewing Defects

to

DEFENSE LOGISTICS AGENCY

Short Term Task Under CLIN 0007 of Contract: DLA 9000-87-D-0018

by

Georgia Institute of Technology
School of Textile & Fiber Engineering

October 1991
In-Process Quality Control In Apparel Production: Sewing Defects

Amended Final Technical Report
Phases I, II & III

October 1991

Report Contents

1.0 Project Overview ................................................. 1
  1.1 Introduction .................................................. 1
  1.2 Project Personnel ............................................. 2

2.0 Research Review ................................................. 2
  2.1 Phase I Review .................................................. 2
  2.2 Phase II Review ................................................. 4
    2.2.1 Data Sampling Rates ...................................... 5
    2.2.2 Aliasing ................................................... 6
    2.2.3 Filtering ................................................ 6
  2.3 Phase III Results ............................................... 7
    2.3.1 Timing and Sample Size .................................. 13
    2.3.2 Data Presentation for Analysis ......................... 13
    2.3.3 Data Evaluated and Results ................................ 13
    2.3.4 Thread Break ............................................... 16
      2.3.4.1 Comparison of Thread/No Thread Curves .......... 17
      2.3.4.2 Machine Speed Effects ................................ 19
      2.3.4.3 Conclusions .......................................... 24
    2.3.5 Thread Tension ........................................... 26
      2.3.5.1 Thread Tension Faults .............................. 28
      2.3.5.2 Thread Balance Considerations .................... 28
    2.3.6 Thread Length Consumption Measurement ................ 31
      2.3.6.1 General .............................................. 31
      2.3.6.2 Results with the Eltex Transducer ................ 31
    2.3.7 Top and Bottom Thread Balance .......................... 34
    2.3.8 Acoustic Measurements of Needle Wear .................. 40

3.0 Plans for the Implementation Phase: Industrial Application . 44
In-Process Quality Control In Apparel Production:
Sewing Defects

1.0 Project Overview

1.1 Introduction

This amended final report correctly identifies the phases of work done under the contract, and adds information omitted earlier which describes in detail the research efforts. While monthly reports did cover the research details, the previous final report did not adequately describe research findings.

This research and development task has the goal of providing an automatic, in-process quality control system for the detection of sewing defects as they occur. Phase I. of research efforts is titled "Defects Assessment" and has as its objective the identification of common types of sewing defects. Phase II., titled "Defect Cause and Detection", has the objective of identifying defect cause and potential real-time means of detection of faults. Phase III., titled 'Technology Demonstration", has as its objective the laboratory implementation of the detection means for defects identified in Phases I and II. This report covers the work done under Phases I, II, and III. A proposal is currently under consideration to implement the results of this work in an industrial environment. Implementation is to occur at sites currently contracting to the government or able to do so. Those sites to be included in the proposed work include commercial and government contractor sites, such as Levi Strauss, Tennessee Apparel and the Factory at DPSC in Philadelphia.

Rapid detection of a sewing defect is important to optimization of the relationship between quality and productivity. Defects found after sewing adversely affect costs. There is distinct advantage to identifying a defect before other operations hinder seam removal and resewing. Also, the automated assembly operations, which are being developed and used in part now and that seen for the future, require on-line quality control if the automation is to succeed. This observation is based upon the current system in which the operator serves as the first line of quality control implementation. Automated sewing stations have no operator to serve in the first line quality control position, leaving quality checks to later stages, after value adding operations are performed on substandard goods. Even multitask workstations need quality control automation, because the operator is handling multiple tasks and is unable to view them all at once. The stress on statistical process control is dependent on automated quality determination in the automated sewing environment.

The research began on March 15, 1989 and has completed its Phase III activities. Additional work was performed in a no cost extension involving graduate thesis research and student special problems. This report follows a series of monthly reports to the DLA which have
detailed regular activities. At the end of seven months a report was prepared as part of the annual reporting of other research groups and a presentation was prepared for the Philadelphia conference. Also, a formal report was prepared in July of 1990, and on two occasions at Cameron Station and once at Clemson University, presentations were made on research accomplishments.

A no cost time extension to the research period has allowed for completion of student projects. Specifically, since funding elapsed, an acoustic approach to identifying needle wear/damage has been found, work on top thread breaks has proceeded with positive results, and an analysis of reliability of acoustic information on thread length consumption has been completed. The latter is important if thread length is to be measured to determine number of ply of fabric. The technical manager of sewing for Levi's stated recently that his first priority was detection of a broken top thread. The research has shown that at least two techniques reliably identify this condition. Additional work is underway to see if infra-red detectors can be used as well, looking at the top thread as it passes over the bobbin case in a lockstitch machine.

1.2 Project Personnel

Dr. L. Howard Olson is the project's principal investigator. Dr. Mathew E. Sikorski is responsible for data collection systems, and Dr. J. Lewis Dorrity is responsible for transducer electronics and data analysis. Dr. Sikorski is on leave of absence at this time awaiting funding of the third phase of this project. The research team management has been to allow shared efforts in all areas and communicate at least weekly on progress and objectives. It has been normal practice for the group to meet daily to discuss results, current needs, and to plan for short and long term objectives.

One M.S. level thesis has resulted from this project. Some eight senior level independent projects have been completed as well. There is a direct benefit to the student and eventually the industry gained through these student efforts.

2.0 Research Review

2.1 Phase I Review

Phase I efforts took two distinct directions of effort. One was to identify sewing defects and in particular to identify those defects which were caused at the sewing machine. The lists of sewing defects discovered by literature search included many defects resulting from fabric or thread defects, but also included defects that were generated at the sewing machine. The second direction of effort was to identify defect detection technologies which might be applied to the defects that were identified. This effort included not only transducer technology, but also data collection and handling...
methods. Kinetic Systems provided a CAMAC crate computer system. A Nicolet 310 digital recording oscilloscope, IBM PC (clone) type processing, and data handling software, such as DaDisp and Igor for the Macintosh PC from Apple, were acquired.

Defects found in the literature had many names and were condensed to a reasonable number in needle, machine, operator and thread categories. Examples of these follow.

**Needle:**
1. Needle picking, fabric damage (burr on needle), needle cuts, blunt needle, needle finish, needle point
2. Needle diameter, incorrect needle size, needle selection

**Machine:**
1. Skipped stitch (chain stitch), broken stitch, bobbin thread runout
2. Unbalanced stitch, stitch length variation

**Operator:**
1. Raw edge, ply misalignment, sewing off of garment

**Thread:**
1. Thread damage, broken stitches, improper spool winding

The literature survey uncovered a glossary of sewing defect terms, but most of the terms did not apply directly to the sewing machine, for example, defects in pressing garments. Dr. Sikorski performed a manual search through Textile Technology Digest for the three years from 1987 through 1989, finding information in the general areas of sewing defects, stitching techniques, sewability tests, sewing dynamics, measurement techniques, types of sewing machines, improvements in sewing machines, computerization in the sewing industry, needle technology, and sewing threads. He also did a survey of transducers.

The article content and Textile Technology Digest abstract number are given in the following for reference.

<table>
<thead>
<tr>
<th>Sewing Defects</th>
<th>Reference TTD #/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewing damage and prevention</td>
<td>5422/87;2038/88</td>
</tr>
<tr>
<td>Zero quality control: Poka-Yoke system</td>
<td>7871/88</td>
</tr>
<tr>
<td>Effect of mech. props. on seam slippage</td>
<td>8609/88;1290/88</td>
</tr>
<tr>
<td>Fabric defects, seam puckering</td>
<td>2835/89</td>
</tr>
<tr>
<td>Relation of plaids to stitching</td>
<td>4525/88;4526/88</td>
</tr>
<tr>
<td>Products to improve sewability</td>
<td>8610/88</td>
</tr>
<tr>
<td>Sewing lubricant</td>
<td>4553/88</td>
</tr>
<tr>
<td>Needle lubrication</td>
<td>462/89</td>
</tr>
<tr>
<td>Factorial study of seam resistance</td>
<td>1291/88</td>
</tr>
</tbody>
</table>

The consideration of transducers included resistive and piezoelectric types of devices. Piezo devices were recommended by instrument manufacturers from point of view of their experience and
success with this type of research effort. The companies with whom contact was made are included in the following list.

Transducer manufacturers:  
Kistler Instrument Co.  
Schaevitz Instrument Co.  
Entran Devices  
Sensor Developments  
BLH Electronics  
Tensitron Inc.  
PCB Piezotronics  
STOW Labs  
Physical Acoustics  
Endevco Corp.

Telephone contact #
(716) 691-5100
(609) 662-8088
(800) 635-0650
(313) 391-3000
(617) 821-2000
(508) 456-3511
(716) 684-0001
(508) 562-9347
(404) 924-6821
(714) 493-8181

Final selection was made of a series of Physical Acoustics piezoelectric transducers and of a piezo based thread motion detector from Eltex of Sweden, located in Greer, SC.

Interestingly, sewing plant managers with whom discussion of sewing defects was held generally looked to current problems as those which are most pressing or in need of a solution. A day spent reviewing returned goods at one plant showed that of the sewing defects, a raw edge or ply fault was the most frequently encountered sewing defect. Defects such as oil spots, missewn labels and the like were not counted.

The summary results of this phase were that ply faults, i.e. two ply vs. three ply under the needle, thread consumption faults, i.e. wrong stitch density and incorrect needle tension, and needle faults, i.e. blunt or fractured needle tips, were indicative of a majority of direct sewing machine related defects.

2.2 Phase II Review

Phase II. research has had the goal of identifying technologies for sensing sewing defects as they occur. This fits into the long term goal of detecting the more common defects and doing so in a cost effective manner. Acceptance of a detection system in the final system analysis relies heavily upon cost of the system. This means that some optimization must occur between the three interacting considerations within the research: sewing defects, sensing method(s), and system cost. That is not to say that Phase II neglected a technology because of cost either.

Sewing machine manufacturers have been one resource of information on commercially available add-on detectors. Sensor manufacturers are the source of specifications and some history of applications. Acoustic emission (AE) or more appropriately, acoustic energy analysis has been the first line of approach in this research. There is a strong history of success with acoustic energy analysis in many industries. The term acoustic emission has been
applied in airframe and similar industries to the analysis of acoustic energy emitted at a microscopic level by metal grain boundary shear and cracks. This work looks at acoustic energy due to sewing machine vibrations through an approach similar to signature analysis. Whereas sound levels in the early development of acoustic emission work were very low, this work dealt with vibrations of major machine components, primarily the sewing needle, and therefore had the benefit of larger amplitude signals. The work was hindered by the fact, discovered in Phase III work, that stitch to stitch variability generated a spectrum of signals that were not so clear as those found in the early emissions work. Techniques had to be developed in Phase III for dealing with data which were obscured by odd events occurring intermixed with regular events.

Because of the more gross nature of the signals with which this research dealt, this analysis is more appropriately referred to as acoustic energy analysis. The key element of the analysis is the detector of the energy. This is a transducer of the type used in acoustic emission work. A variety of transducers are available. The transducers currently in use in this research are grouped as follows: (1) Physical Acoustics piezoelectric units, model 59223 (20 - 100 kHz), model R-15/C (50 - 200 kHz), and WD (100 - 1200 kHz); (2) Realistic electret microphone, model 33-1052; (3) Eltex single end yarn motion detector; and (4) Spectral Dynamics M99 accelerometer. The accelerometer is attached to the base of the sewing machine by a magnetic coupling and by bolt down. The Physical Acoustics units are coupled with a coupling grease, and the electret microphone is air coupled. The Physical Acoustics transducers were purchased with a 60 dB amplifier (selectable 40 - 60 dB), which also provides transducer bias, and a 0 - 40 dB postamplifier.

There are several considerations which must be added to simple acquisition of transducers and data recording instrumentation to avoid false information. In particular consideration is given to data sampling rate and its influence on data validity, i.e. aliasing and the need for filtering.

2.2.1 Data Sampling Rates

The analysis of data from engineering experiments has been greatly facilitated by advances in computer and software technologies. One of the main steps in such analysis is to digitize the signals from transducer devices. In doing this, one must be aware of the Nyquist (sampling) theorem. This theorem states that the minimum frequency which can be used for digitization without losing information is twice the highest frequency of interest. This is described in many texts, and one which describes well the reasoning behind the theorem is Kuo.
Kuo derives the transformation from the time domain to the frequency domain which shows that a sampler is a harmonic generator. The text illustrates the replication of a signal spectrum at intervals of the sampling frequency, $w_s$. As $w_s$ approaches the highest signal frequency, $w_c$, the sidebands begin to overlap the original signal spectrum thereby giving erroneous or false results. The closer the frequency of interest is to $w_c$, the more erroneous the results. Thus the theoretical limit is stated as above. Practical filter design makes it prudent to sample at a somewhat higher rate, perhaps $w_s > 3w_c$. A filter with a cutoff frequency "close to" the highest frequency of interest should be employed to prevent the generation of false output information.

2.2.2 Aliasing

Another problem which can occur in digital sampling is called aliasing. This is a problem which causes a frequency to appear to be much lower in frequency. This may be visually observed when using a strobe light with a rotating object. When the flash (sampling) frequency is lower than the frequency of rotation, the object appears to be rotating at a different frequency than it actually is. The original waveform occurs at one sampling rate while the aliased signal occurs at a rate one fifteenth as fast. This causes the observed signal to be less than the actual signal.

At first, the two problems discussed above may seem to be the same phenomenon. However, in the first case there is a non-existent waveform appearing superimposed on a real waveform and in the second case an existing waveform appears at a different frequency than it actually is.

2.2.3 Filtering

From the above discussion, a conclusion should be that frequencies above those of interest or approaching the sampling limitation must be attenuated. This may be done electronically by using operational amplifiers and appropriate feedback circuits. In this method the filtered waveform is sampled and analyzed. The alternative is digital filtering.

Digital filtering may also be employed by calling appropriate software algorithms in the computer. If real time processing is needed and the sampling rate requirement is too high, then the digital algorithm may not be fast enough. One must also be aware that filters are not ideal. Frequencies near cutoff, while reduced by a certain db of loss, may still be present in the sampled signal. This relates to filter circuit Q, or quality factor. A Kronhite analog filter with bandpass, high pass, and lowpass selections over

---

1 Kuo, Benjamin C., Analysis and Synthesis of Sampled-Data Control Systems, Prentice-Hall, 1964
the frequency range 0 - 1,000 kHz has been chosen for this research.

2.3 Phase III Results

This phase of research began the in earnest identification of means of detecting sewing defects and demonstrating on the laboratory equipment that it could indeed be done. While originally the lab facility at Southern College of Technology was proposed for doing demonstrations of the lab setup, a laboratory was set aside at Georgia Tech for the apparel research so that research would not be interrupted by transporting equipment off site. The following describes the developments in this phase of research.

Defects such as thread line presence and number of fabric ply have been investigated by means of acoustic analysis. The steps involved include taking numerous data points and applying a Fast Fourier Transform to the data to acquire a spectrum of amplitude versus frequency. Because of phase differences in energy emitted at each cycle of the sewing machine, time domain data cannot be averaged. On the other hand, data transformed to the frequency domain can indeed be averaged over multiple cycles, smoothed, and thereby analyzed for differences in spectra when defects are introduced.

The purpose of the initial efforts at data acquisition were to test the acquisition system and the data packages. The JUKI sewing machine provides in the electronic controller a top of cycle or bottom of cycle pulse for triggering data acquisition. Included below successively are figures of a signal made while the machine is running over a single layer of fabric and a noise signal amplified to be of similar amplitude to the running signal.

![Signal Data](image)

Figure 1 Signal from Operating Machine
The noise image similar to the above in Figure 1 is shown in Figure 2 following.

**Figure 2 Amplified Noise Data**

Both images have the same number of data points and the same sampling frequency (1024 points, 500ns interval). Expanding the noise signal leads to finding what appears to be periodic information. The true test of noise versus interesting content comes with analysis by means of the Fast Fourier Transform (FFT) and the spectrum (normalized, real portion).

To illustrate this the spectra of both Figures 1 and 2 are represented respectively by Figures 3 and 4. These follow on the next page.

The spectra clearly show which has periodic signal content and which has none. The noise signal rests on or at the zero axis, indicating no amplitude was found at any particular frequency. The operating signal has something happening at 15 to 30 kHz and perhaps harmonics or other signals at 45 to 60 kHz.
Figure 3 Spectrum of Data with Signal

Figure 4 Spectrum of Noise Data
The FFT is done on periodic functions. The fixed interval data sample has discontinuity at the ends. There is an effect on the spectrum caused by the energy artificially generated by the data edges. Routines which taper the end points of a non-periodic signal so that they match is referred to as a windowing function. Several known by name are the Hamming, Hanning and Kaiser functions. To see the effect of the window on the signal spectrum, the following two figures give the data equivalent to that in Figure 1 and Figure 3 with the Hanning window applied.

Figure 5 Signal Data with Hanning Window

Figure 5 above indicates only the shape of the windowing function when compared to Figure 1. The purpose of doing this is to determine if windowing alters the spectrum. For that the next figure illustrates the spectrum after windowing.
Superimposing these two shows that the frequencies remain intact. Amplitude is changed somewhat, but that significance is not certain at this time.

The above does indicate that techniques such as averaging of data over five or ten cycles, or averaging the spectra may be useful in detecting rapidly where changes occur due to process changes. There is a significant amount of process and random noise outside the acoustic energy related to process change for which detection is needed. This is part of the early work necessary to set up efficient investigation of sewing defects.

An ambitious program was set forth to gather data in an orderly fashion to begin the search for an acoustic signature which indicated the number of plies of fabric being penetrated by the needle. There is an early indication that some success may be had in this approach. Neither the raw data nor a spectrum alone is sufficient to identify the number of plies of fabric under the needle. But taking the difference between two spectra with one and two plies, for example, shows promise at frequencies of about 5 and 15 kHz, and at 8.80 kHz.
for a machine speed of 2000 RPM.

Figure 7. Following is of the difference between two spectra taken at one ply and at two ply. Each waveform data specimen of 4000 data points had covered about two machine cycles. Five data specimens were taken at each ply level, one and two. Spectra were calculated for each data specimen; and the average of the five spectra in each set was used to form the difference spectrum shown below.

![One - Two Ply Spectra Difference](image)

**Figure 7** Preliminary Data on Ply Spectra Difference

The significant peak at 8.80 kHz suggests that a single frequency narrowband sample at this frequency would be sufficient to discern between one and two ply. This result led to further research on fabric ply detection, particularly at higher speeds.
2.3.1 Timing and Sample Size

The data collected was done at a sewing machine speed of 3000 RPM and at a 10 usec sampling rate on the Nicolet 310. Sewing at 3000 RPM is equivalent to 50 cycles per second or, taking the reciprocal, 20,000 usec. per cycle. The Nicolet collects 4000 points per data sample, and at 10 usec. per point will collect 40,000 usec. of data. This then corresponds to exactly two cycles of the sewing machine. With the time continuity of each sample assured, the triggering of the start point of each sample remains to have equivalent samples for analysis work.

Triggering fortunately is provided on the JUKI sewing machine by a Hall effect type device mounted on the machine flywheel (handwheel). The triggering is repeatable on successive cycles at constant operating speed. The trigger point is at top dead center. This means that duplicate sets of data were available and in integral number of cycles per sample set. The concatenation of raw data prior to FFT analysis is one use of these controlled data sets. Secondly, the FFT algorithm relies upon having a power of two as the length of the data set. If a discontinuity is introduced into the data by adding artificial data to the end of a data set, e.g. 4000 data points plus 96 zeroes, then a piece of artificial information is added to the FFT. Data presentation for analysis should have 4096 valid data points.

2.3.2 Data Presentation for Analysis

With integral machine cycle data increments, it is sufficiently easy to duplicate the first 96 data points as the last 96 points in a set of 4096 data points for the analysis software. The FORTRAN software which was prepared for reading the binary data off of Nicolet disks also gives essential information headers about the data, groups successive sets of data in lots of five sets, fills the data to 4096 data points, and reformats the internal representation of the data to ASCII representation with six decimal places. With the work that has been done to write Igor macros for the actual analysis, the system is reasonably automated. That is to say that in about thirty minutes on the lab computer (an IBM PC), an Igor ready disk can be prepared from a Nicolet disk. Incidentally there are multiple Igor disks involved in completely resolving all the data on a Nicolet disk. Then in an additional thirty minutes, Igor can provide FFT magnitude spectrums of the data on a Macintosh. Five spectrums are generated and averaged in a typical analysis group.

Images created on the Mac have been successfully transported in TIF format from the Mac to an IBM PC and vice versa. The images in this report happen to be regenerated from Mac data using Lotus 1-2-3 rather than being TIF files.

2.3.3 Data Evaluated and Results

The data taken was for one fabric ply under the sewing head, two
ply, and three ply. The acoustic sensor was coupled to the bed plate near the needle. Twenty five samples were taken at each fabric ply level. This is seen as providing certainty through averaging of random noise and false signals, the goal of taking large data sets. Each ply level was thus represented by fifty cycles of the sewing machine.

At 6500 kHrz approximately there were pronounced peaks in each of the data sets (1, 2, 3 ply) which were quite similar in magnitude. The data at these peaks and elsewhere along the curves despite the averaging of 50 sets was "bumpy", having oscillations in magnitude while also having very clear trends. Curve smoothing using a Pascal triangle approach resulted in removing many of the bumps.

At 8765 Hz there were peaks which clearly showed some effect was taking place. Figure 8 following illustrates the bumpy data and trend seen in the 8500 - 9000 Hz increment.

![Figure 8](image)

Figure 8 Twenty Five Data Sets Averaged

This data represents the averaging of twenty five spectrums or the magnitude of twenty five FFT's. Despite the benefit of averaging data, there is a roughness to the data. The next step was to smooth the data. An example of smoothing is shown in Figure 9. This represents the data in Figure 8 smoothed by a (1,4,6,4,1) weighting of surrounding data, the weighting being taken from Pascal's triangle. This was done in a spreadsheet from numbers given by Igor in a 0 - 50,000 Hz spectrum.
This appears much more acceptable. If there is any problem with the smoothed data, it is that there appears to be a non-linear relation between number of ply and the acoustic response at about 8765 Hz. Incidentally, the figure of 8765 Hz was found by manually searching the Igor spectrum for the peak value and observing that it was consistent from one ply level's data set to the next.

Recalling the consistency in amplitude found at just over 6500 Hz, normalization was tried by dividing all the data by the data value average in the 6500 - 6550 Hz range. The result of doing this gave the best appearance of plotted data yet obtained. The effects of normalization and smoothing are shown in Figure 10 below.
The data in the 8725 to 8775 Hz range show a nearly linear step size from one to two to three ply. This is as clear and as promising as one could expect of a research result. The next question is what precautions should be taken. Later research showed that significant samples only could provide reliable results. The ideal of a single stitch ply fault detector is an unreasonable expectation on a lockstitch machine.

Investigation of acoustic signals before and after a thread break shows that there is good correlation with a band of frequencies at 6000 to 7000 Hz and at 8700 to 8800 Hz. There was found in the data a recurring peak, as well, at 14.5 kHz.

### 2.3.4 Thread Break

There are one or two additional observations that can be made at this time. The data shows a broad decrease in the total energy of the spectrum as the change from thread in the needle to no thread in the needle is made. The no thread condition has the lower amplitude generally.
A demonstration was made with the M99-1 accelerometer screwed directly to the machine bed. The output was directed through an accelerometer amplifier to a filter, then an audio amplifier and audio loud speaker. The change in sound made by the machine as the thread was cut was clearly discernible. This demonstration suggests strongly that a method of detecting thread breaks could be based on an integration of fixed period of the accelerometer signal.

Both raw data, which has the appearance of an amplitude modulated wave, and the spectrum yield information about what is occurring in the sewing area. Dr. Sikorski noted that he could hear a sound change when the thread broke. Indeed, the average power in the emissions decreases when the thread breaks. This is indeed significant when considering the simplicity and therefore cost of detection means. Direct analog filtering and voltage comparison is inexpensive to accomplish. On sewing machines with built in microprocessors, more sophisticated analysis may occur.

A series of extended runs was made to investigate the frequency content of acoustic signals before and after simulated thread breaks. All of the data were obtained thus far at a machine speed of 3000 RPM after a very careful tension adjustment for the needle and bobbin threads to produce "normal" stitches.

The experimental procedure consisted in obtaining between 30 and 35 wave recordings with the help of the Nicolet 310 oscilloscope. Curves obtained in this manner represented "normal" sewing conditions. The second set of 30 or more wave recordings was obtained when the machine was run without the thread in the needle simulating the thread break condition. The thread vs. no thread curves were then compared with the help of the Igor and DADiSP software packages.

2.3.4.1 Comparison of Thread/No Thread Curves

There are distinct frequency bands that might be useful for the detection of thread breaks. These are: (1) 6000 to 7500 Hz; (2) 8700 to 8800 Hz and (3) 14000 to 16000 Hz (particularly the lower part of this latter band). Since band (2) is being considered for possible use in the determination of the number of fabric ply, an evaluation is given only for bands (1) and (3).

The DADiSP software, installed in an IBM PC/XT computer, allowed the extraction of sections of experimental curves, thus simulating electronic filtering. In addition, it was possible to determine quantities such as areas under curves, mean values of signals in selected frequency bands, as well as the ratio of these quantities under thread/no thread comparison conditions.

The curves obtained for thread vs. no thread are illustrated in the next figure.
An example will now be given of the comparison of the "thread" (T) vs. "no thread" (NT) curves in frequency bands (1) and (3) defined above.

In band (1) the acoustic energy decreased when the needle thread was cut while the opposite was found to be true for band (3).

The results for band (1) were as follows:

\[ \text{Area}(T) = 253 \text{ V-Hz} \]

( V-Hz is taken as the units of area under the FFT spectrum curve being analyzed: V, volts amplitude (Y-axis) vs. Hz, frequency (X-axis) )
Area(NT)=156 V-Hz and Area(T)/Area(NT)=1.63 V-Hz and
Mean(T) =0.083 V
Mean(NT)=0.053 V and Mean(T)/Mean(NT)=1.57 V

Similarly, the results for band (3) were:
Area(T) =121 V-Hz
Area(NT)=229 V-Hz and Area(NT)/Area(T)=2.20 V-Hz
Mean(T) =0.072 V
Mean(NT)=0.158 V and Mean(NT)/Mean(T)=1.89 V

The above results show that the observed changes in the experimental curves with needle thread and without are large enough to warrant the use of these effects for the construction of a thread break detector. This would require construction of electronic filters centered around frequencies of 6500 and 15000 Hz for the two bands (1) and (3) considered.

The status of acoustic energy analysis applied to sewing is that thread breaks are positively identified. Integration over the spectra or filtering and summing two or three frequencies can accomplish this. A filter circuit with a Q factor of 100 may be sufficient to detect thread break faults. Op amp (operational amplifier) active filtering can achieve the Q so long as parts tolerance in held at a high level or compensation is used at the time of circuit design. The next step is considering machine speed over the feasible range of apparel plant operations.

The work was extended to encompass the following eight sewing machine speeds: 1680, 2127, 2564, 2985, 3389, 3846, 4255 and 4651. Careful tension adjustments were made for the needle and bobbin threads in order to produce normal stitches. For the evaluation of each experimental condition four waves were imported into DADiSP and then analyzed. The analysis consisted of obtaining frequency spectra of each of the waves and getting an average spectrum for further study.

2.3.4.2 Machine Speed Effects

The illustrations in this section depict general characteristics of sound spectra recorded in the frequency range 0-25kHz for different sewing machine speeds. Figure 12 shows average spectra of sound waves obtained during normal sewing of two ply of utility trouser fabric. The upper curve corresponds to a machine speed of 4255 RPM and the lower one to 2985 RPM. Both of the curves are typical of normal sewing with the needle and bobbin threads being properly pre-tensioned.
Figure 12  Direct Comparison of Effect of Sewing Speed on Spectra

The purpose of Fig. 12 is to illustrate that both curves are similar in shape; however, the 4255 RPM curve is characterized by a much greater acoustic output.
The next two figures illustrate a different comparison, namely, sewing both with and without the needle thread. Figure 13 depicts average acoustic spectra of acoustic waves under Thread (T) and No Thread (NT) conditions obtained at a machine speed of 1680 RPM.

![Spectra With and Without Thread](image)

**Figure 13** Low Speed Comparison of Thread vs. No Thread

Figure 14 on the next page shows similar data except obtained at a machine speed of 4255 RPM.
Observe the reversal of the relative position of thread and no thread curves between figures 13 and 14.

Spectra With and Without Thread
Thd. vs. No Thd. @ 4255 RPM

Figure 14 High Speed Comparison of Thread vs. No Thread

The significant difference between the two cases is that the acoustic output for the 1680 RPM (NT) curve is much lower, almost in the entire frequency band, than for the (T) curve. The situation is reversed in the 4255 RPM case. The acoustic output is greater for the (NT) curve. This condition was also found to be true for all remaining six machine speeds investigated (see Figs. 15 and 16).
Figure 15 Difference in Thread - No Thread Spectra vs. Speed

Figure 16 Ratio of Thread - No Thread Spectra vs. Speed
In Fig. 15 differences (and in Fig. 16 ratios) between the calculated areas under the No Thread and Thread spectral curves, as well as mean voltage values for these are plotted against the sewing machine speeds. Note that the points for the 1680 RPM curves are located below the zero line in accordance with the results presented in Fig 16, above. These results point to the fact that the acoustic outputs for Thread and No Thread conditions in the spectral range of 1-25kHz are equal somewhere in the vicinity if 2000 RPM.

In the next section detailed results are presented to illustrate the approach that has been developed to build a thread break detector based on sewing machine acoustics.

2.3.4.3 Conclusions

A number of frequency bands were selected for possible use in the detection of thread breaks. An updated listing of these bands, based upon these figures, is as follows: (1) 4.0-7.3 kHz; (2) 13.5-16.5 kHz; (3) 19.0-20.3 kHz and (4) 13.5-20.3 kHz. Band No. (4) includes the acoustic content of bands (2) and (3).

The DADiSP software was used to perform filtering or band selection of the 0-25 kHz spectra into the bands given above. After performing the above extractions, it was possible to calculate the areas under the curves and the mean values of signals in the selected frequency bands. Figure 17 shows the combined results for the above listed four frequency bands of an evaluation of the difference of areas under no thread/thread comparison conditions for the different sewing machine RPM.
Figure 17 Thread - No Thread Differences in Passband Increments

The contents of band (1) behave quite differently from that of all the other bands. While the acoustic signal of band (1) decreases when there is no needle thread, that of the other three bands increases. Parenthetically, band (4) combines the output of bands (2) and (3) and augments it by an additional range of 16.5-19.0 kHz. Consequently, the area difference for band (4) is greater than the sum of the corresponding quantities for bands (2) and (3).

A thread break detector could be built by monitoring the output from electronic filters for extracting signals from frequency bands (1) and (4). For machine speeds lower than 2000 RPM, a thread break would be characterized by a sudden decrease in acoustic energy (at a constant sewing speed). For sewing speeds greater than 2000 RPM, a thread break would result in a sudden increase in monitored acoustic output.
2.3.5 Thread Tension

Thread tension produces a defect when top to bottom thread tensions become severely imbalanced. This affects lockstitch formation, determining whether the junction of top and bottom threads is adequately hidden from the surface of the fabric ply structure. Too much top tension causes the bobbin thread to be pulled completely to the upper surface of the fabric. This is a visual defect as well as one which reduces seam abrasion resistance. The FFT of a series of stitches changes visibly when the tension is off to the top or bottom. Acoustic measurement offers sufficient promise to merit its use in this application.

Five data sets related to needle and bobbin thread tensions have been analyzed using DADiSP software. The extractions of spectral data were made in similarity with the evaluation of thread break results. However, only two frequency bands were taken, namely, 4.0-7.3 kHz and 7.3-21.5 kHz in addition to the broadband data for 0-25 kHz. A graphical representation of the tension results is given in Fig. 18, below.

![Average Spectral Response](image)

**Figure 18** Area Under Spectrum, Various Bands
Figure 18 shows the results obtained on five sets of data rendered for the following experimental conditions: (1) Normal needle thread tension (NT) and normal bobbin thread tension (NB); (2) NT and low bobbin thread tension (LB); (3) Low needle thread tension (LT) and high bobbin thread tension (HB); (4) LT and NB and (5) LT and also LB. The points for the three frequency bands carry different designations. Each point represents an average of four data sets.

The results of Fig. 18 indicate that it should be possible to detect a number of sewing defects by monitoring signals from one or more electronic filters. For example, the difference between conditions NT, LB and LT, NB should be detectable using the low frequency band signal. However, in order to be able to distinguish between the three low needle tension conditions, it may be necessary to also monitor the high or broadband frequency signals.

In summary, both thread break and abnormal tension conditions in the needle and bobbin threads appear to be amenable to the acoustic energy analysis.

To better quantify the experimental results, measurements were taken of the needle thread tensions as a function of the position of the thread tensioning knob and of the bobbin thread tension by noting different positions of the spring tension adjustment screw. First, needle tension results are presented.

![Tension Setting](image.png)

**Figure 19** Thread Tension and Machine Setting
Figure 19 shows experimental results on the tension values of the needle thread as a function of position of the tensioning knob. The zero position corresponds to the proximal surface of the knob being flush with the end of the shaft of the tensioning attachment. Each point on the graph is an average of ten measurements made using two Ohaus spring scales graduated in grams. The ranges of these scales were: 0-250 g and 0-2000 g. Only full turns of the knob were considered. Measurements of this type should be very useful in quantifying future experimental work on other types of machine.

The thread tension in the bobbin was evaluated with the help of the spring scale with the range 0-250 g. It takes approximately 1.5 turns of the screw to go from an essentially zero tension to a maximum of 125 g for an extreme clockwise position of the tightening screw. Average values for ten measurements were: for 0.5 turn, $T=12$ g; for 1.0 turn, $T=75$ g and for 1.5 turns, $T=125$ g with a pronounced stick-slip effect. For optimum sewing conditions the screw setting should be between 0.5 and 1.0 turns.

2.3.5.1 Thread Tension Faults

In discussion above, average spectral responses are displayed in Fig. 18 for different experimental conditions and various frequency bands. The quantities plotted were for the area under different spectral bands. Preliminary data were obtained for the output voltage generated in the 4.0-7.3 kHz band for different experimental conditions. The voltages were measured using a general purpose Beckman 310 multimeter.

The following general results are given for sewing of two ply of fabric at 2100 RPM and 46 dB of signal amplification:
- For normal needle and bobbin tensions the approximate output voltage $[V\text{(out)}]$ from the transducer was about 0.3 Volts AC;
- For conditions of high needle and bobbin tensions $V\text{(out)}=0.4$ Volts AC;
- Finally, for low needle and bobbin tensions $V\text{(out)}=0.2$ Volts AC.

More accurate results may be obtained using a meter that reads true RMS voltage values. The significance of this is that an inexpensive device can be designed to detect thread tension variation from a normal value range.

2.3.5.2 Thread Balance Considerations

For a denim fabric and a reasonable needle thread tension, the distance from bottom to top from the interlock point was closer to 25%-75% than 50%-50%. The needle thread looped the bobbin thread near the bottom of the fabric ply. This condition was attained when the top thread tension was kept sufficiently high to prevent loop formation on the bottom of the fabric but not high enough to cause
the puckering of the fabric after sewing.

In all cases, including that of perfect balance for two plies of fabric, i.e., when the needle thread and bobbin thread lengths are equal in a two ply seam, the needle thread was shorter than the bobbin thread for one ply and longer for three plies. In all studies the bobbin thread tension was kept low, at approximately 20 gm.

Figure 20 illustrates both the needle tension effects on the length balance sewing two plies of fabric, as well as the effects of one and three plies on the length ratio.

To further emphasize the ply effects, the needle tension was set at 250 gm and the length balance values were obtained for five samples each of one, two and three plies sewn. The results are given in Fig. 21. This figure, which was taken from work done in a special problems undergraduate project, namely Danna Kelley's project report, illustrates that as the number of fabric plies sewn increases, so does the amount of needle thread consumed in the fabric.
On the basis of the above results, a direct measurement of consumed needle thread, such as could be accomplished by passing the thread over a pulley attached to a low friction encoder, might be the simplest method to differentiate between sewing one or more plies of fabric.

Room temperature and humidity appeared to have a significant effect on the needle tension needed to establish a thread length balance. Danna Kelley reported in her paper that on hot and humid days the thread length balance approached unity close to a needle thread tension of 450 gm, whereas on cool and dry days the corresponding needle tension was as high as 700 gm. Thread finish, the oily or waxy surface lubricant applied by the manufacturer, probably accounts for the humidity sensitivity of thread balance to top thread tension.
These results suggest that further work is needed in this area in order to establish the factors that cause such a significant difference in the findings. Possible causes might be associated with mechanical and frictional properties of the thread used, for example.

2.3.6 Thread Length Consumption Measurement

2.3.6.1 General

A novel experimental method was used to directly measure the time in each machine cycle during which the needle thread is being pulled. The method involved the use of an Eltex piezoelectric transducer. Eltex transducers have been used in the past to monitor yarn breaks in a number of textile manufacturing operations.

2.3.6.2 Results with the Eltex Transducer

Figure 22 shows a superposition of signals obtained with the Eltex transducer while sewing one and two ply of fabric. To obtain this data the transducer was placed between the two tensioning heads located on the front of the Juki sewing machine. The needle thread coming from the first (upper) tensioner was inserted into the "eye" of the transducer and then fed into the lower tensioner so that there were relatively short segments of the needle thread between the transducer and the tensioning heads.

![Comparison of Eltex Signals](image)

*Figure 22* Eltex Data, Three Ply and One Ply Pulses
The electronic signals were captured with the help of Nicolet 310 digital oscilloscope and then processed on our IBM PC XT using DADiSP software. The difference between the dropout signals for one and three ply sewing was found to be about 0.7 msec.

Figure 23 illustrates the difference in duration between the single ply signal and that for an empty bobbin condition. To be able to obtain the latter signal the fabric had to be carefully pushed in the direction of the sewing machine bed in order to allow pulling of the thread through the eye of the needle during sewing. It is evident that this case represents the condition of the least consumption of thread, i.e., the length of thread pulled corresponds to the length of fabric that has traversed under the presser foot.

The above experimental technique will allow a quantitative definition of what it means to have a normal, high or low thread tension both in the needle and bobbin threads. This approach should also be helpful in the detection of sewing defects due to accidental fabric slippage during sewing.

Comparison of Eltex Data

Figure 23 Empty Bobbin vs. Normal One Ply Response
The initial experiments using the Eltex piezoelectric transducer, which are described above, clearly showed that the time during which the needle thread is being drawn by the take-up lever is about one tenth of the machine cycle. Specifically, for a 2100 RPM speed of the sewing machine, one cycle takes about 28.6 ms. While sewing one and three ply of the utility trouser fabric, the corresponding times of thread pull vs. machine cycle were 10.1 % and 12.9 %, respectively.

Therefore, to attain a better understanding of these complex relationships, measurements were made of the relative positions of the needle and the take-up lever. This was accomplished by measuring the position of the needle with reference to the top of the machine bed using a ruler, and the position of the eyelet of the take-up lever using a cathetometer which was located on the floor of the laboratory about four feet away from the sewing machine.

Two measurements were made for each position of the handwheel. The method used for marking the wheel is described below.

A special tape containing 24 white and black regions was attached to the circumference of the handwheel to allow angular positioning of the handwheel from a fixed marker on the body of the sewing machine next to the handwheel. The angular spacing from the edge of one black region to the next amounted to 15 degrees. Data in Fig. 24 was collected in increments representing an angle of rotation of 15 degrees.

The zero(0) on this axis corresponds to the alignment of two timing (red) dots, one on the handwheel and the other on the body of the sewing machine. Another standard position is 30 degrees forward and corresponds to the position of the handwheel (and of the needle) automatically assumed by the sewing machine when stopped. In this case the horizontal alignment is between another pair of timing (white and red) dots.
The ordinate of Fig.24 represents both the vertical positions of a fixed point on the mount of the needle and the approximate center of the eyelet in the take-up lever referenced to their lowest point of travel. The two curves are appropriately identified in the figure. This representation was intended to compare the relative positions of the needle and the take-up lever for the same angular position of the handwheel.

2.3.7 Top and Bottom Thread Balance

A study was undertaken of uniformity and balance of top thread consumption. The needle thread is referred to as the top thread, and the bobbin thread is the bottom thread. This study was done in support of the previous work with the Eltex sensor which gave a measure of thread consumption on the needle side with each machine.
Variability found in the Eltex data was assessed to be the result of yarn deformation and mass per unit length variation. To further assess this variability, this work was undertaken and is presented in the following.

An experimental procedure was developed wherein a two ply fabric was sewn under conditions of fixed stitch setting and machine speed. The average stitch density was 3.8 stitches per cm. with about 0.4 cm consumption of thread per stitch from each the top and bottom thread sources. Machine speed was mid-range at 3000 RPM.

The primary variable of the study is top thread tension. Advice from several technical staff members of sewing installations led to the conclusion that bobbin tension is held to a minimum subject to the constraint that enough tension be present to assure stability of bobbin thread delivery. A check of bobbins said to be at the correct setting of tension found that the tension was close to 20 g. The value chosen for bobbin tension was that of 20 g, which was checked each day of data collection.

Top thread tensions were varied between having the bobbin thread not pulled into the fabric ply, to having the bobbin thread pulled nearly to the top of the fabric ply. Special attention was paid to having balance of the top and bottom thread loops such that they meet in the middle of the fabric ply.

The data collection procedure was to select successive 10 cm. lengths of fabric and dissect each length for top thread in the first and bottom thread in the second. This was done by cutting each loop in the opposing thread set of stitches so that the thread of concern in that section could be removed intact. The length of thread was measured and is in fact preserved in a research notebook.

Data from the work is seen in two figures following. The variability was sufficient that the day of data collection was an influence on the data. While this is of itself not the reason for variability, temperature and humidity conditions did change remarkably during the period of the test. Fabric and sewing thread finishes are sensitive to conditions at the time of a test. Adding to this density variability of the thread and fabric accounts for variability in the results. Figure 25., following, is of data collected.
There appears to be some relation of the ratio of top and bottom thread lengths and top thread tension in Figure 25. The curve has an appearance similar to an exponential decay function, which could be related to the exponential tension ratio function used to describe friction in wrapping or over curved surfaces.

In the vicinity of 450 g, the fabric appears to be in balance with a ratio of top to bottom thread length approaching 1.0. The replications that day gave rise to some confidence in machine settings. This balance, it is now found, is disturbed by changing environmental conditions. Very cool, dry outside air and a failed environmental control system led to very dry conditions in the lab.

Evidently, this markedly affected the sewing process. Figure 26 below is of data taken during the time of these uncontrolled conditions. It shows more variability and less of a trend for top thread position to follow top thread tension.
Here the tension range of 425 g to 450 g gives almost 30% change in the thread balance. Friction and fabric/yarn variability are having a serious affect on sewing. One conclusion of the look at thread balance is to conclude that uniformity, including that of the environment, has considerable effect on sewing.

Because of this variability due to sewing room conditions, a third set of fabrics were sewn with varying top thread tension. Incidentally, top and bottom threads were removed from one hundred stitch seam lengths in these tests to get a reasonably accurate measure of top and bottom stitch lengths.

Note that conditions other than sewing room environmental conditions are the same in the figures 25. and 26 above, and figure 27 following.
Figure 27. Thread Balance in a Lockstitch Seam

On this date, balance, which is the ratio of needle to bobbin thread consumption of 1.0, occurs at about 700 grams thread tension. Later work with sewing plants and maintenance personnel pointed to a standard value of 200 grams for the needle (or top) thread tension. At that tension level, more than twice as much top thread is consumed, compared with bobbin thread consumption. Clearly, the balance point is not at the center of the ply being sewn, but rather two thirds of the distance from top to bottom, close to the bottom side.

To operate at excess tension in order to form a more "perfect" lockstitch creates the potential for thread breaks. The sewing thread has thick and thin places to some degree in any circumstance. Work by another student found the stress-strain relation for the sewing thread. This is shown in figure 28. following.
This figure shows that achieving balance may take about 50% of the total yarn strength. Preloading the yarn to this extent is of itself reasonably safe, but when sewing loads during fabric penetration and loop formation are considered, this increases the chance for thread breaks significantly. The value recommended for top thread tension, again, is about 200g.

The take-up consumption is affected by thread tension and number of plies, notably whether or not the same length of thread is consumed at each stitch, and by the stitches per inch. Therefore, a consumption variation can result from one or more basic sewing defects. Thread consumption in sewing has the chance of being detected by the Eltex piezoelectric sensor, and because it has been used successfully in other textile applications, the device is seen as a reliable, acceptable tool for apparel application. A thread or yarn thin place can undergo excessive elongation after the consumption sensor, which causes a false reading of a short stitch. This is not a sewing defect, but rather a thread defect. Similarly, changes in yarn finish with humidity and temperature were seen in figures just above to cause changes in thread balance for fixed
tension settings. This too is a thread problem of another type.

Variability at each needle penetration of the fabric affects how easily or simply a circuit can be designed to do a measurement. One study showed that some measurement techniques cannot find a single stitch fault. Fortunately, single stitch faults are not consequential to many seams in apparel manufacturing. For example, seam "blow out" in washing of Navy utility trousers at the felled seam occurs only when ten or so stitches are misformed. This fault is detectable overall. Whereas the first misformed stitch produces a signal which falls at the extreme of an allowable error zone, ten such stitches produce an average which falls over a warning limit.

2.3.8 Acoustic Measurements of Needle Wear

A series of experimental runs were made by Bernard Gunn, a M.S. level graduate student working with Dr. Sikorski, to check if there are significant differences between the acoustic spectra for different conditions of wear of sewing needles. The assumption was that should there be a measurable difference in the acoustic energy generated during sewing between a fresh and a worn sewing needle, it should be possible to devise automatic means to alert the machine operator as to when a worn needle should be replaced.

The experiments were conducted by placing a small piezoelectric transducer on the body of the sewing machine in the vicinity of the needle shaft and away from the throat plate. This prevented possible interference of the transducer with the sewing process. The amplifier gain was set at 52dB to bring the electrical signal into the workable range of the Nicolet 310 digital oscilloscope.

The experimental procedure was as follows. The acoustic spectral signatures were obtained for two needles, one brand new with a sharp tip and the other with a mechanically abraded tip to a radius about five times greater than the new needle. Four traces for each needle were then analyzed with the help of DADiSP software. The frequency range analyzed was 0-25 kHz. After obtaining four FFT spectra, an average spectrum for each needle was generated and the results compared. Areas under the average spectra were used to compare the two needle conditions. The variability of areas from trace to trace for each needle was also evaluated in addition to obtaining the areas for each average spectrum. The results obtained were an average and range for each:

\[ \text{Area (sharp needle)} = (329.9 \pm 32.5) \text{ Volt x Hertz} \]
\[ \text{Area (worn needle)} = (422.6 \pm 140.2) \text{ Volt x Hertz}. \]

These results show that the acoustic energy generated by the blunted needle was about 28% greater than for the new, sharp needle. The variability of areas from experiment to experiment was about 33% for the blunted needle compared to about 10% for the new needle. The
above results were obtained for a fixed sewing speed of 2100 RPM.

The results reported above suggest the feasibility of developing a needle wear detector. An RMS voltage signal generated by the transducer during a short run of sewing at a constant RPM could be compared with the previously recorded value for a new needle. In this way the operator could be alerted when the needle reaches a pre-determined amount of wear.

Further research done under a no cost extension to the project allowed for completion and reporting on student special projects and this graduate thesis. Needles blunted intentionally, and used needles from industrial sources were used to collect information on their spectra versus degree of wear as determined by measuring the radius of curvature of the needle tip under a scanning electron microscope. The factory at DPSC was quite helpful in producing needles with wear of four, eight and twelve hours. Results of measurement of tip curvature is given in Figure 29. following.

![Figure 29. Tip Curvature, DPSC Samples](image)

The needles from DPSC allowed data to be collected via acoustic energy analysis that showed a clear relation of energy to wear in one passband. A bandpass filter centered at 10500 Hz, Q of about 100, would see 0.5v output for a new needle, 0.7v after four hours and
0.9v after eight hours of use, based upon the transducer and amplifier used in the student's tests. The relation was almost linear. Most sewing operations change the needle every eight hours, or about one million cycles of the needle.

Needles are surface hardened to withstand the abrasion of sewing. The observation of needle tips under a scanning electron microscope showed that about 25% of all needles sent to us from industry were found to have broken tips. The needles were specified as simply having been taken out of service without regard for reason. The tip breaks had the characteristic surface of brittle fracture in metal. This suggests that these breaks were caused by striking something solid. This may be fasteners on the apparel or parts of the sewing machine that are out of alignment or misadjusted. Assistance to Mr. Gunn's thesis were given by Tom Hammonds and Abubakar Bah.

Additional information is presently available on the acoustic measurements of needle wear. The comparison of acoustic energy generated by the blunted needles as compared with the new, sharp needle indicates a 28.4% increase for the less blunted needle and 38.1% for the more blunted one.

The FFT spectra for the three needles are shown in figure 30.

![Figure 30. Needle Wear Comparison](image-url)
The 4-7 kHz frequency window does not allow the differentiation between the two blunted needles. However, two other frequency bands, one around 10 kHz and the other centered around 20 kHz do. Narrow frequency band filters around the latter two center frequencies could be used for the evaluation of the degree of wear of such needles.

Eight "worn", or rejected Schmetz needles were obtained through the courtesy of the Tennessee Apparel Corporation. These needles were used in high speed (5000 RPM) Duerkopf 211 sewing machines for sewing GORTEX fabrics. Microscopy showed that these needles have blunted tips, and others of different design show mechanical damage in the vicinity of the needle's eye. Another rejected needle was obtained through the courtesy of the Southern Tech Apparel Research Center, a 134 CL SUK Schmetz medium ball sewing needle which was used for sewing pockets in utility denim trousers on an Adler 804 sewing machine. A visual comparison of this and a new needle indicated a minor roughening of the tip of the used needle and a very severe wear of the sides of the needle on both sides of the needle eye, causing thread breaks.

A student, Arlene Stark, continued work on measuring the acoustic spectra of the sewing machine in conditions of thread versus no thread in normal two ply seaming. Her research added 3000 RPM data to that which was found earlier. The following came from this work.

--- Thread vs. No Thread Spectra

**Comparison at 3000 RPM**

![Graph showing Thread vs. No Thread Spectra](image)

*Figure 31. Thread v. No Thread (Normal RPM)*
Figure 31 illustrates again that a frequency band can be found where thread break can be identified. Efforts to determine whether integration of the area under the curve is sufficient had difficulty at low frequency. This concept was to have an all purpose, all frequency thread break detector. For reasonable sewing speeds, it is possible to use an op amp integrator, but research indicated that the broad approach would not be adequate at all speeds. Most industrial sewing is done at fixed speed. Furthermore, the new sewing machine drives achieve operating speed in about ten stitch cycles. The result is that fixed band detection should be reliable.

Research into fiber optic detection of top thread as it passes over the bobbin case led to the determination that this method is feasible as well. The findings included that straight fiber optics were insufficient to both detect a missing top thread and provide sufficient clearance for bobbin changing. When an integral lens is included with the fiber optics, reliable thread detection was achieved with an optimum placement from the bobbin case of 2.5" separation. This allows adequate clearance.

3.0 Plans for the Implementation Phase: Industrial Application

Designs for the low-cost circuits to implement fault detection are to be generated and built in prototype form. In-plant testing of the prototypes will be conducted at least two facilities, but more likely three facilities. Levi Strauss through their Technical Center in Richardson, TX, Tennessee Apparel and the Factory at DPSC in Philadelphia are strong candidates for the on site tests. Also, the Johnson & Johnson sewing plant in El Paso, TX has offered its facilities for this prototype development effort. Levis will coordinate design efforts for their application at Richardson, then permit tests in the regional plant most suited to the particular application. Similarly, technical or maintenance personnel at Tennessee Apparel and at the DPSC Factory will be consulted during prototype development. The key element is rapid feedback from the plants, allowing time for redesign and refinement in the design process. The final report for the Implementation Phase is to be written such that independent firms or individuals may duplicate what was done in this project.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING:
DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK

Volume I: Final Technical Report

Research sponsored by

Defense Logistics Agency
DLA-PRM
Cameron Station
Alexandria, Virginia

DLA Contract #: DLA-900-87-D-0018-0003

Reported by:

Dr. Sundaresan Jayaraman
Principal Investigator

Georgia Institute of Technology
School of Textile & Fiber Engineering
Atlanta, GA 30332-0295

Tel: 404-894-2490
Fax: 404-894-8780

Georgia Tech Project #: E-27-637

November 1988 - November 1991

SJ-TR-DEFE-9202
Research has been carried out to analyze defects in apparel manufacturing. Two knowledge-based software systems -- FDAS (Fabric Defects Analysis System) and SDAS (Sewing Defects Analysis System) -- have been developed. The research has been funded by the U.S. Defense Logistics Agency under contract number DLA-900-87-D-0018-0003.

FDAS covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. SDAS covers the defects occurring in the cutting, sewing, finishing and packing departments of an apparel plant producing denim trousers. Based on the visual description of the defect in the fabric (type, orientation and mode of repetition of the defect), FDAS identifies the defect and suggests possible causes and remedies.

(Continued on reverse)
Research Project Personnel

**K. Srinivasan**  
Graduate Research Assistant

**Dr. Krishna Parachuru**  
**Dr. Phiroze H. Dastoor**  
Research Investigators

**Dr. Sundaresan Jayaraman**  
Principal Investigator
ACKNOWLEDGMENTS

This research project was funded by the U.S. Defense Logistics Agency (DLA) under contract number DLA-900-87-D-0018-0003. The authors would like to thank Mr. Donald F. O’Brien, Mr. Daniel Gearing, Ms. Helen Kerlin and Ms. Julie Tsao of DLA for making this research endeavor possible. Ms. Diana Burton from Defense Personnel Support Center in Philadelphia provided useful input during the course of the project.

Mr. Bob Springfield and Ms. Ann O’Neill of Georgia Tech Research Institute (GTRI) deserve thanks for their help in developing the defects questionnaire. Thanks are also due to the Steering Committee of the Georgia Tech/Southern Tech Apparel Manufacturing Technology Center (AMTC) for its help in refining the questionnaire. The American Apparel Manufacturers Association (AAMA) assisted in mailing the questionnaire to the apparel industry. AAMA and the respondents to the questionnaire deserve appreciation and thanks for their participation in the research work.

Several textile/apparel companies hosted the researchers on plant visits and provided valuable input. Among them, Coastal Industries, Cone Mills, Dowling Textiles, Graniteville Industries, Levi Strauss, Oxford Slacks, Swift Textiles and Tennessee Apparel deserve special mention. Professor Larry Haddock, Mr. Bill Cameron, Mr. Harry Pettigrew and Ms. Carol Ring shared their apparel expertise; their contributions to the project are thankfully acknowledged.

Mr. John Adams, Ms. Susan Shows and Dr. Wayne Tincher of AMTC provided the necessary administrative support during the course of this research and their efforts are thankfully acknowledged. Finally, thanks are due Georgia Tech research administration for providing the matching funds to acquire the necessary hardware and software to carry out this research.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>vii</td>
</tr>
<tr>
<td><strong>1. INTRODUCTION</strong></td>
<td></td>
</tr>
<tr>
<td>1.1 Scope of the Endeavor</td>
<td>1</td>
</tr>
<tr>
<td><strong>2. OVERVIEW AND RESEARCH METHODOLOGY</strong></td>
<td></td>
</tr>
<tr>
<td>2.1 Current Defects Detection and Analysis Procedures</td>
<td>3</td>
</tr>
<tr>
<td>2.2 Garment Assembly Defects vs. Fabric Manufacturing Defects</td>
<td>5</td>
</tr>
<tr>
<td>2.3 Interviews and Interactions with Industry and Government</td>
<td>6</td>
</tr>
<tr>
<td>2.4 Fabric Defects: Knowledge Acquisition and Collation</td>
<td>7</td>
</tr>
<tr>
<td>2.5 Fabric Defects: Representation and Reasoning</td>
<td>7</td>
</tr>
<tr>
<td>2.6 Fabric Defects: Software Implementation of the Analysis Framework</td>
<td>8</td>
</tr>
<tr>
<td>2.7 Sewing Defects: Knowledge Acquisition and Collation</td>
<td>10</td>
</tr>
<tr>
<td>2.8 Sewing Defects: Representation and Reasoning</td>
<td>11</td>
</tr>
<tr>
<td>2.9 Sewing Defects: Software Implementation of the Analysis Framework</td>
<td>12</td>
</tr>
<tr>
<td>2.10 Database Integration with FDAS and SDAS</td>
<td>13</td>
</tr>
<tr>
<td>2.11 Testing and Debugging</td>
<td>13</td>
</tr>
<tr>
<td>2.12 Generalization and Recommendations</td>
<td>14</td>
</tr>
<tr>
<td>**3. PRELIMINARY INTERVIEWS AND INTERACTION WITH INDUSTRY AND GOVERNMENT</td>
<td></td>
</tr>
<tr>
<td>3.1 Development of Questionnaires</td>
<td>16</td>
</tr>
<tr>
<td>3.2 Analysis of the two Questionnaires</td>
<td>17</td>
</tr>
<tr>
<td>3.3 Plant Trips and Industrial Visits</td>
<td>17</td>
</tr>
<tr>
<td><strong>4. FABRIC DEFECTS: KNOWLEDGE ACQUISITION</strong></td>
<td></td>
</tr>
<tr>
<td>4.1 Sources of Knowledge on Fabric Defects</td>
<td>20</td>
</tr>
<tr>
<td>4.2 Defect Occurrence and Causes</td>
<td>22</td>
</tr>
<tr>
<td>4.3 Literature Review: Computers in Other Interpretation and Diagnosis Tasks</td>
<td>24</td>
</tr>
<tr>
<td>4.4 Literature Review: Human-Computer Interface</td>
<td>27</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>5.</td>
<td>FABRIC DEFECTS: REPRESENTATION AND REASONING</td>
</tr>
<tr>
<td>5.1</td>
<td>Classification Scheme</td>
</tr>
<tr>
<td>5.2</td>
<td>Analysis of Defects: Diagnosis</td>
</tr>
<tr>
<td>5.3</td>
<td>Selection of KBS Software Tools</td>
</tr>
<tr>
<td>6.</td>
<td>FABRIC DEFECTS: SOFTWARE IMPLEMENTATION OF ANALYSIS FRAMEWORK</td>
</tr>
<tr>
<td>6.1</td>
<td>Class-Object Representation</td>
</tr>
<tr>
<td>6.2</td>
<td>Three-tier Rule Base</td>
</tr>
<tr>
<td>6.3</td>
<td>User Interface</td>
</tr>
<tr>
<td>7.</td>
<td>SEWING DEFECTS: ACQUISITION AND COLLATION OF KNOWLEDGE</td>
</tr>
<tr>
<td>7.1</td>
<td>Garment Defects: Sources of Knowledge</td>
</tr>
<tr>
<td>7.2</td>
<td>Classification Scheme</td>
</tr>
<tr>
<td>7.3</td>
<td>Defect Occurrences and Causal Factors</td>
</tr>
<tr>
<td>7.4</td>
<td>Special Defects Arising in Denim Trouser Assembly</td>
</tr>
<tr>
<td>8.</td>
<td>SEWING DEFECTS: REPRESENTATION AND REASONING</td>
</tr>
<tr>
<td>8.1</td>
<td>Partitioning the Set of Defects</td>
</tr>
<tr>
<td>8.2</td>
<td>Structuring the Diagnosis Knowledge</td>
</tr>
<tr>
<td>8.3</td>
<td>Representing the MIL-STD-87062A Garment Specifications</td>
</tr>
<tr>
<td>9.</td>
<td>SEWING DEFECTS: SOFTWARE IMPLEMENTATION OF ANALYSIS FRAMEWORK</td>
</tr>
<tr>
<td>9.1</td>
<td>Working Principles: Analysis and Diagnosis</td>
</tr>
<tr>
<td>9.2</td>
<td>Speed and Size</td>
</tr>
<tr>
<td>9.3</td>
<td>Modularity and Ease of Customization</td>
</tr>
<tr>
<td>10.</td>
<td>DATABASE INTEGRATION WITH FDAS AND SDAS</td>
</tr>
<tr>
<td>10.1</td>
<td>Database Schema</td>
</tr>
<tr>
<td>10.2</td>
<td>Communication with the Database</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Research has been carried out to analyze defects in apparel manufacturing. Two knowledge-based software systems -- FDAS (Fabric Defects Analysis System) and SDAS (Sewing Defects Analysis System) -- have been developed. The research has been funded by the U.S. Defense Logistics Agency under contract number DLA-900-87-D-0018-0003.

FDAS covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. SDAS covers the defects occurring in the cutting, sewing, finishing and packing departments of an apparel plant producing denim trousers. Based on the visual description of the defect in the fabric (type, orientation and mode of repetition of the defect), FDAS identifies the defect and suggests possible causes and remedies.

SDAS uses information on the location and nature of the defect to identify the manufacturing operation causing the defect and displays possible causes and remedies for the defect. SDAS also has a provision to display the relevant construction specifications (MIL-SPEC) for the assembly operation causing the defect. Both FDAS and SDAS are implemented in Nexpert Object and are linked to a relational data base using Oracle. They run under both MS-DOS and Unix environments. Software manuals for using FDAS and SDAS have been produced.

FDAS is intended for use at the greige or finished fabric inspection station in a weaving plant. It can also serve as a backend to a vision-based inspection system. SDAS can be used by an apparel plant for the inspection of trousers.

About the Report: The final technical report is presented in three volumes. In Volume I (the present volume), the details of the research effort are discussed along with recommendations for additional research. Volume II is the software user manual for FDAS, while Volume III is the software user manual for SDAS.
CHAPTER 1
INTRODUCTION

The U.S. apparel industry is currently undergoing rapid changes to operate successfully in a highly competitive global market. One obvious way of being successful is to significantly improve the quality of domestic products. In addition to fetching a premium price, improved product quality accounts for customer satisfaction and consistent consumer demand.

The increasing emphasis in the apparel industry on "on-line" quality control highlights another important application of this research effort. Every assembly operation in trouser/apparel manufacturing adds value to the product. The detection of a defect and initiation of remedial measures right at the stage at which the defect occurs will mean not only fewer defective garments but also reduced wastage of production resources. Thus, there is a need to simplify on-line quality control procedures, to set up a formalized approach for tracking defects occurrence and to analyze their causes with the primary goal of instituting remedial measures.

Many apparel plants, as they function today in the United States, do not maintain an accurate record of quality performance on a day-to-day basis. A continuous tracking and recording of defects is essential to positively influence quality levels over an extended period of time. Quality records must be maintained not only for the plant as a whole but also for the various production equipment and individual operators.

Considering all the above factors, it is clear that there is a need not only to investigate the problem of defects in garment manufacturing but also to build an intelligent system that can record, identify and diagnose defects occurring in garment manufacturing.

1.1 Scope of the Endeavor

The primary objective of the research effort is to develop a knowledge-based system to analyze the causes of defects in apparel manufacturing and to suggest remedies to correct them. This would be a turn-key software product, with primary application to the domain of utility denim trousers (MIL-87062A). This area was chosen from the world of military apparel, keeping in mind the large numbers of utility trousers procured by the military every year, and the rigid construction specifications and quality norms that this procurement is to meet. In all, the domain of denim utility trousers constitutes a significant yet manageable, portion of the overall apparel market.

The research agenda was broken up into three broad phases. These divisions represent not only the executed chronological sequence but also the set of formally defined sub-stages whose results are useful in and of themselves.

Phase I: The first phase consisted of an in-depth investigation into the current practice of analyzing and classifying defects, including the economic impact of defects in trouser manufacturing operations. The observable factors of defects and their definitions were recorded. Typical con-
tractual requirements and established contract quality levels were studied. Also, general specifications such as description of the objectives and requirements of the product, and constraints/parameters of operations were noted. Applicable standards (MIL-STD-105D, MIL-I-45208) and classification schemes developed by major apparel manufacturers were utilized as guidelines. A critical review of past research in this area covering government publications, apparel journals and computer science and knowledge-based systems literature was performed.

**Phase II:** The second phase covered the development of a classification scheme and analysis paradigm for the whole range of defects and their possible causes and remedies. This phase was undertaken with the intended purpose of expressing the organized information in computerized form, and it included a ranking scheme for defects and a list of suggested remedies. Applicable specifications such as MIL-T-87062A which lay down quality norms for men’s denim utility trousers, were used as the primary source of guidance. Selection of suitable hardware and software tools was also completed in Phase II.

**Phase III:** The third and final phase consisted of the implementation of the knowledge framework in software and testing for refinement and verification. Research in computer-aided defects classification/diagnosis in other areas of engineering was examined with the intention of adopting the useful concepts and techniques.

The **finalized** software product has been demonstrated to the research sponsor (the U.S. Defense Logistics Agency), other government agencies and the textile/apparel industry. Product documentation manuals are also available for delivery along with the software.
CHAPTER 2

OVERVIEW AND RESEARCH METHODOLOGY

This chapter is an overview of the next nine chapters. It provides a comprehensive account of the research project. Most of the section headings in this chapter correspond to an entire chapter in the subsequent pages of this report.

2.1 Current Defects Detection and Analysis Procedures

2.1.1 Denim Fabrics

Most producers of denim fabrics in the U.S. carry out 100% inspection at the finished folding stage. Since denims are made with indigo-dyed yarn, the question of greige fabric inspection does not arise in denim manufacture. Inspection at the finished fabric stage serves the following functions:

a) Elimination of fabric flaws that are unacceptable to apparel manufacturers, and consumers in general.

b) Tagging minor flaws. Usually, tags are used on one or both sides of the fabric to indicate the location of the fault to the spreader. Tags of different colors are sometimes used to convey information about the nature of the flaw.

c) Control of yarn and fabric quality on the basis of day-to-day recording of defect occurrences.

d) Sorting of fabric production in accordance with defect levels.

e) In some cases, sharing of fabric defects information with the apparel manufacturer. Defect statistics are recorded for each roll and each sort delivered to the garment manufacturer.

Fabric Grading Systems: The two fabric grading systems currently being used by the U.S. textile industry are the 10-point system and the 4-point system. Both systems identify defects, and assign a demerit point value for each defect, based on the seriousness of the defect.

The 10-point grading system assigns points for warp-way faults based on four standard imperfection sizes as follows:

| Up to 1" | 1 point |
| 1" - 5" | 2 points |
| 5" - 10" | 5 points |
| 10" - 36" | 10 points |

Filling-way defects ranging from 5" to half the width of the fabric are assigned 5 points. Defects exceeding half the fabric width are assigned 10 points. No yard of fabric is assigned more than 10 demerit points no matter how bad or how frequent the defects are. The total number of defect points recorded is compared against the number of yards in the inspected piece. If the number of penalty points does not exceed the number of linear yards, the fabric is considered a first
quality fabric. If the fabric width is greater than 50", up to 10% more penalty points are allowed for a first quality classification. Also, greige fabrics that are to be subsequently printed are allowed 50% more penalty points.

The 4-point grading system also assigns demerit points to individual defects, but the basis for point assignment is different from that of the 10-point system. The standard point assignments for different defect extents are as follows:

- 3" or less: 1 point
- > 3" but < 6": 2 points
- > 6" but < 9": 3 points
- > 9": 4 points

Not more than 4 demerit points are assignable to a single yard of fabric; the total number of points are normally figured on the basis of 100 square yards. The acceptable level of quality can vary between buyers and sellers. Generally, not more than 40 penalty points are acceptable in 100 square yards of a first-quality fabric.

The 4-point system has the broadest base of support. In addition to the ASQC and the National Association of Sportswear Manufacturers, the Federal government and the AAMA have endorsed the 4-point system.

2.1.2 Finished Denim Trousers

The trouser manufacturing industry has no standard procedures for the inspection and grading of assembled trousers. The variations arise from the fact that no two plants producing a similar product experience the same type of defects with similar or nearly equal frequencies. The type and frequency of defects produced in a particular plant appear to be a characteristic of the production equipment used and the general manufacturing environment prevalent in the plant. Thus, while oil stains and loose threads may be the most common faults in one plant, these problems may not be that common in some other plant that produces the same or similar garment. The emphasis laid on the detection and correction of individual faults will therefore be different at different manufacturing plants.

There is also a wide variation in the resources employed for the detection and correction of faults occurring in the cutting and sewing processes. The number of persons dealing with Quality Control on the shop-floor varies anywhere between 0% and 18% of the production employees. There are also large variations in the human resources employed for in-process and finished garment inspection.

In general, inspection and QC procedures followed by a particular plant appear to reflect the quality requirements specified by the purchaser. Other factors that significantly influence the inspection and QC mechanism are the complexity of the garment’s design, the type of production equipment available, and the volume of the production order.

In-process inspection is generally restricted to a percentage of the intermediate products; the exact percentage selected for inspection is, again, highly variable. In-process inspection is also
linked to the distribution of day-to-day defect generation in the sewing room. The QC Manager assigns inspectors to trouble spots. Inspection records are maintained by each in-process inspector, and rejected bundles are usually tagged and re-routed to the respective operator. Thus, wastage due to defects is minimized.

Finished garment inspection is usually carried out on the entire production run. The plant’s output is classified, usually into three categories: *first quality garments, seconds* and *irregulars*.

### 2.2 Garment Assembly Defects vs. Fabric Manufacturing Defects

During the course of this research, it was found that yarn and fabric manufacturing processes accounted for anywhere between 30-70% of the defects in finished trousers. The exact contribution of the yarn and fabric manufacturing processes and the garment assembly process will depend to a large extent on the manufacturing process and the technology employed.

The large-scale use of open-end spinning machines and high-speed air-jet looms for yarn and fabric production, respectively, have considerably reduced the extent of yarn and fabric flaws seen in finished garments. At the same time, a few defects that are typically characteristic of the new technologies have been added to the list of possible flaws in the finished garments. However, in terms of overall impact on garment quality, these new types of defects are much less severe than the defects generated by the older manufacturing technologies that have been replaced.

In the apparel plant, too, new types of spreading and cutting machines and sewing equipment can contribute previously-unseen types of defects; however, the overall level of defects and their severity is always positively influenced by modernization of machinery or process. The relative contribution of the textile and apparel processes to defect generation is also very much a function of the garment type involved. Complicated garment design and construction coupled with tight sewing quality specifications will make it difficult to control cutting and sewing flaws within reasonable limits.

Due to the very large share of defect generation arising from yarn and fabric manufacture, it became clear during the early stages of the research that the project goals would be best served by splitting the effort into two software systems instead of one. One of the software products would deal exclusively with the tracking, analysis, classification and diagnosis of fabric defects. The other software product would perform similar tasks for defects arising out of the garment assembly process. While this decision to proceed with two simultaneous development efforts undoubtedly increased the volume of research work, any other alternative would not have led to the realization of the project goals.

**Need for two software systems:** Another major reason for having two sister software systems was the mutually exclusive utility of such software. Fabric manufacturers very seldom operate their own garment assembly plants, and almost always sell their product to independent apparel makers. Such textile plants would benefit from a fabric defects analysis system, but would not have any use for garment defects analysis software. Similarly, apparel manufacturers are rarely integrated from yarn spinning to garment manufacture. Their primary concern is about quality viola-
tions in the garment manufacturing process. They have no direct control over the correction of yarn and fabric defects. Consequently, they cannot use the fabric defects analysis software as an in-process quality control tool. However, they would be interested in gathering and reporting data on fabric defects to their suppliers.

A secondary rationale was the size and complexity of the overall software system. Two separate software systems, one for fabric defects analysis (FDAS) and the other for sewing defects analysis (SDAS), would certainly result in smaller sizes of each, and these would be easier to test, learn and use. Also, they could be much more easily customized to the needs of a particular manufacturing organization, since they were more precisely targeted in the first place.

The likely users of the systems may be classified into two broad categories. The first class of users are the fabric or garment inspectors, who will be using their respective defects diagnosis/classification systems repeatedly during the course of their work. The main function of the software in these cases is to serve as a recording device, and to flag the out-of-tolerance conditions that merit attention from technical personnel. The second class of users comprises the technical personnel themselves, who will be consulting FDAS or SDAS for corrective information pertaining to frequently occurring and difficult-to-diagnose defects. The latter group will be very much interested in the reasoning of FDAS or SDAS in coming to a conclusion. However, the first group of users may not be interested in all the details, which may slow down the rate of inspection.

2.3 Interviews and Interactions with Industry and Government

Two questionnaires were designed to receive feedback from the industry on fabric flaws and sewing defects. The questionnaires were intended to elicit information, in a structured way, from apparel industry executives about their experiences with tracking and controlling defects. It was hoped that the questionnaires would draw enough detailed answers to yield statistically meaningful information about problem areas, the economic implications of the various classes of defects and current industrial QC schemes.

The first questionnaire sought information on defect classification norms, in-plant testing and evaluation procedures (for fabric, thread and trim), the nature of fabric flaws, the nature of sewing flaws, the relative proportion of fabric versus sewing defects, the qualifications and experience of quality control personnel, and details of the quality control programs in place.

The second questionnaire sought information on the economic impact of different defects and defect classes. This information was sought for the manufacturing organization as a whole, to get a picture of price realization of defects and the overall economic impact suffered at different defect levels.

Over the course of the project, the members of the research team made trips to several apparel and fabric producers in Georgia and neighboring states. The impetus behind such visits was to get a first-hand idea of the production resources employed in the manufacture of military utility apparel, and to have technical discussions with their managerial and QC personnel. Among the fabric producers were Cone Mills and Swift Textiles, who manufacture a large percentage of
the denim sold today to apparel manufacturers. Apparel manufacturers included commercial vend-
dors such as Levi Strauss, and military contractors such as Tennessee Apparel, Dowling Textiles
and Coastal Industries. The research team also worked very closely with apparel manufacturing
experts at the Southern College of Technology, the site of the Apparel Manufacturing Technology
Center (AMTC). The software systems were largely based on the input received from such experts.

More details on this subject can be found in Chapter 3.

2.4 Fabric Defects: Knowledge Acquisition and Collation

FDAS (Fabric Defects Analysis System) is intended to be an identification and diagnosis
system for defects encountered in woven fabrics. The system covers the common manufacturing
defects occurring in greige and finished fabrics, including those in indigo-dyed denims. In its
present form, FDAS is ideally suited for indigo-dyed denim fabrics. However, the system can be
used by any weaving or finishing plant because it has the knowledge for the analysis of defects oc-
curring in these processes. Classification and analysis of defect occurrences on a day-to-day basis
will be helpful in maximizing the percentage of first quality production. The system can be located
at the greige/finished fabric inspection station or at the tenter frame to record and classify defect
occurrences on a continuous production basis.

The primary source of information on fabric defects was the expertise of the members of
the research team who had a very strong background and understanding of the whole range of tex-
tile manufacturing processes.

Other sources of information used were the major Federal Specifications relevant to fabric
and garment manufacturing and the defects arising therefrom (MIL-STD-1488F, MIL-STD-
87062A, Federal Standard #4B), textbooks and an MS thesis on fabric defects. A detailed listing
of all the references and sources of information can be found in Chapter 4.

An exhaustive listing of fabric defects was then compiled, together with all the different
modes of occurrence of each defect in the fabric. For each defect, a thorough investigation was
conducted on all possible causes: arising from the material itself, from the process, from poor orga-
nizational practices, etc. A set of feasible correction measures was also listed for each defect in its
many manifestations. Since the industry currently uses several different combinations of machin-
ery and processes to make the final denim product, there may be several plausible remedies that
may be applied for a given flaw. Additionally, newer technologies which have assumed dominance
in denim manufacture, such as open-end spinning and air-jet weaving, contribute their own unique
set of defects.

In parallel with knowledge acquisition and collation, research was carried out to understand
the latest developments in the design of knowledge-based systems for diagnosis.

2.5 Fabric Defects: Representation and Reasoning

After several attempts, a necessary, yet sufficient scheme of classifying fabric defects based
on their visual characteristics was developed. There were four major visual cues: the type of defect, the defect’s direction in the fabric, the defect’s mode of occurrence (in both warp and filling directions) and the appearance of the defect. It was found that all fabric defects can be uniquely classified using these visual characteristics which can be readily identified by human inspectors. Also, future attempts to develop a fully automated inspection system using a front-end consisting of a vision system would find it exceptionally easy to deal with this set of visual cues as output parameters\(^1\).

This scheme is very simple and classifies the entire set of fabric faults into groups according to the four discriminating visual attributes. A single defect can occur in several groups, depending on the factors that caused it. Also, some groupings in the classification scheme may have very few defects, or even none (usually owing to physical impossibility). This is elaborated further in Chapter 4.

The representation chosen for this defects analysis software followed an associational model, because of certain technical limitations of a causal model (please see Chapter 5). Using the Nexpert Object shell from Neuron Data, Inc., the entities in the fabric defects domain were represented in a class-object hierarchy. The class hierarchies are very useful in structuring the knowledge base, and in making it modular. Also, when reasoning over this knowledge base using search, pruning techniques to arrive at quick decisions regarding defects work well with such a hierarchically structured representation.

First, FDAS assembles information about the current defect, as seen by the user. The user indicates the values of the salient visual features of the defect, mentioned previously. After receiving information on the visual characteristics of the defect, the software compiles a list of all possible fabric defects that share the particular visual description. It does this by rule-based search for that group of defects which all show the visual characteristics given by the user. FDAS now presents a precise description of each individual defect within this group, and allows the user to decide which description exactly matches the defect under review. This matching of defect description with the actual defect is the final step in the identification process. Having pinpointed the exact nature of the defect currently being analyzed, the software then displays an analysis of the defect by listing the possible causes and remedies.

The diagnosis information for FDAS is contained in text files in the computer. Once a defect is identified precisely, FDAS retrieves the appropriate diagnosis information file and displays it. This arrangement makes it very convenient for an organization to customize the diagnosis files according to its manufacturing process and needs.

### 2.6 Fabric Defects: Software Implementation of the Analysis Framework

A commercial knowledge-based system building tool called Nexpert Object® was chosen to be the main implementation vehicle for this research work. This type of "shell" allows the pro-

---

1. At the recently concluded international textile machinery show (ITMA '91) in September, 1991, Elbit Vision Systems of Israel exhibited an automatic fabric inspection system. Coincidently, their classification scheme mirrors the one implemented in FDAS; thus FDAS can serve as a backend to the Elbit system to totally automate the fabric inspection process.
grammer to work at a higher conceptual level than conventional symbolic languages such as LISP. Nexpert Object has a wealth of tools for rule-based programming and a reasonably good object-oriented paradigm. It provides communication with database systems, requires little programming expertise, and is relatively inexpensive. For purposes of software development, its incremental compilation features are also very useful.

The second component of the FDAS software framework is the Oracle® database management system (DBMS). Tables within the database record the defect information communicated to it from the FDAS defects knowledge base (in Nexpert) during each diagnosis cycle. The database keeps a long-term record of defects, which can then be examined and analyzed to find out pertinent information regarding defects according to time period, material type, loom number, shift, etc. Such a database also permits a careful and quantitative evaluation of the beneficial effects of any improvements made in the manufacturing process or QC procedures.

FDAS consists of a class-object hierarchy of entities in the fabric defects domain, with rules to perform the deduction task and manipulate these entities. The class-object hierarchy in this representation is the chief basis for the separation of domain knowledge and control knowledge; two separate class hierarchies are used, one for the representation of fabric defects themselves and their attributes, and another for controlling the focus of the search process.

The reasoning method used with this hierarchical representation is search, using several techniques to accomplish early pruning. The overall rule base is grouped into three levels. The first level of rules tries to define in which defect "Type" category (Point, Line or Area) the defect falls, according to the input from the user. The search process then narrows the defects domain using the second level of rules to a group, or sub-class, of defects sharing the same or similar set of visual attributes. The last level of rules explores the match of every defect description in this group with the appearance of the current defect as interpreted by the user.

At every level, redundant search is minimized by taking advantage of several inference controlling mechanisms available in Nexpert to recognize the successful completion of a sub-goal, such as finding an appropriate sub-class of defects. Another feature of the classification scheme is that the degree of sparseness varies considerably. That is, some defect sub-classes have only a few defect descriptions, while other defect groups have twenty or more. In the case of the more crowded groups, the defects which lie within the group are further divided into appropriate subclasses. While this poses one more question to the user, it reduces the overall complexity of the software.

The current size of FDAS stands at 450 rules, including those for communicating with the Oracle database. The size of the knowledge base is not unduly large, considering that it treats about 95 individual defects with a combined total of about 350 occurrence modes. The analysis/diagnosis time is less than 10-20 seconds in most cases, depending on the complexity of the fabric defect seen and the training of the operator. Because of this short cycle time, FDAS can be used on the shop-floor.

For the UNIX version of FDAS, a graphics interface based on the SunView window system has been developed. Using several levels of menus and pop-up panels to ask questions and to inter-
act with the user, this interface greatly simplifies the use of the software and reduces training time. For the DOS delivery version of FDAS, a similar menu-based user interface has been developed using Nexpert Forms.

FDAS is fairly complex, and adding new defects to the knowledge base requires some effort, especially to understand the details of the class-object representation and the rule levels. On the other hand, it is extremely easy to change the diagnosis information, which is independent of FDAS and is resident in text files. Such diagnosis modifications do not entail any interaction with Nexpert. This trade-off in complexity is reasonable; it is far more likely that an organization will tailor the system’s advisory output to its manufacturing processes and parameters and much less likely that it will need to add newer defects to the system.

2.7 Sewing Defects: Knowledge Acquisition and Collation

SDAS (Sewing Defects Analysis System) is a knowledge-based software system meant for the identification and diagnosis of sewing defects encountered in the manufacture of utility denim trousers to military specifications. The system covers predominantly sewing faults. While SDAS is designed to work for the assembly sequences recommended for trouser manufacturing, it can be extended to cover defects analysis for other garment types with additional effort. Classification and analysis of defect occurrences on a daily basis will be helpful in maximizing the percentage of first quality production, operator assessment, machine monitoring and production planning. The system is currently meant for use at the finished garment inspection station; it can also be modified for working with only certain segments of the production process for in-process inspection.

Several books such as the "Apparel Manufacturing Handbook" by Solinger, and "Guide to Apparel Manufacturing" by Peyton Hudson were used initially to gain knowledge about the garment production process and to get acquainted with the design and manufacturing methods and the terminology. Military specifications dealing with utility trouser construction (MIL-STD-87062A), garment quality evaluation (MIL-STD-1488F) and seams and stitches (Federal Standard #751a) constituted a very important set of guidelines for delineating the garment defects domain. Some of these specifications, such as the construction sequences laid down in MIL-STD-87062A, had direct influence on the structure of the software. A complete listing of the references used for deriving knowledge about the trouser manufacturing process is provided in Chapter 6.

The most important sources for information relating to the analysis of defects were the apparel experts at AMTC. Regular meetings were held with the AMTC personnel for technical discussions and their opinion was sought extensively on several aspects of software design and implementation.

The classification of sewing defects centered around the location of the defect, the nature of the defect, and the relevant recommendations for such a defect. These classification criteria were found to be adequate to describe each defect uniquely and to advise on the defect's causes and remedies. One of the military specifications (MIL-STD-87062A) was directly incorporated in the SDAS software to provide a ready reference on the construction standards.
There are some manufacturing considerations unique to the construction of denim utility trouser that set it apart from the assembly of other garments. One of these is the extremely stiff nature of the fabric, which makes defects such as seam pucker not only relatively uncommon in assembly but also easy to contend with. Another is the very simple construction of the garment, which has far fewer operations than other trouser assembly sequences. This contributes to fewer chances of errors at pattern design and cutting, bundle mix-ups, etc. A third point of interest is the preponderance of double-felled double-lapped seams, which contribute to a large percentage of certain types of sewing flaws. These will be described in detail in Chapter 7.

2.8 Sewing Defects: Representation and Reasoning

The sewing defects classification uses a scheme which is structured around two main criteria: the location of the defect, and the nature of the defect. These are the two major visual cues that an inspector derives during the inspection of the garment. The "Nature of Defect" heading is further classified into an elaborate decomposition with several sub-classes such as Seam Formation Defects, Stitch Formation Defects, Garment Appearance Defects, Defective Trim, and so on. This classification has been fully developed for sewing defects in the current version of SDAS, and can be extended for specific defects in other categories, if deemed useful. The "Location of Defect" is the other major heading, sub-classified only for the complex structural elements such as the flies. There is also a specification hierarchy which contains construction norms, with the relevant specifications being referred to for each defect being classified by SDAS.

The hierarchy trees are expressed as class-object structures, for purposes of modularity and ease of testing and future modification. All defect classification entities and their groupings are classes, and their contents are the individual types of defects, the defect location, etc. This set of class-object structures also affords a measure of commonality for expressing defect analysis schemes for other garments, at a later time.

The external working of SDAS is as simple as that of FDAS. The user is presented with a pair of selection panels, one for indication of the nature of the defect and another for the defect's location on the garment. After receiving the important visual information from the user, SDAS proceeds to deduce the assembly operation responsible for such a defect, by a rule-based search for the manufacturing operation(s) that may be causing the defect. If more than one manufacturing operation could cause this defect, then further questions are posed to the user about the character of the flaw until an accurate conclusion can be reached. Once the assembly step has been pinned down, the type of defect is further analyzed to determine its exact origin and to decide if it had been caused by an operator or by the machine. For every defect, there is a generalized diagnosis available; also, if there are specialized remedial measures to be taken for that defect when seen at a particular location on the garment, these are readily displayed. As in the case of FDAS, the corrective measures are contained in text files, to facilitate their easy modification and customization. The Nexpert programs of SDAS deal with the representation of the defect knowledge, as well as the running of each diagnosis cycle.

After each diagnosis, SDAS asks if the user wishes to scan the construction standards defined in the MIL-STD-87062A for the operation to which the defect was traced. These assembly
specifications are also stored within SDAS, as class-object hierarchies. After some more search to determine the appropriate specifications, these are displayed for the user's reference.

2.9 Sewing Defects: Software Implementation of the Analysis Framework

As in the case of FDAS, the main software vehicle used to construct the SDAS program was Nexpert Object. Software development particularly benefited from Nexpert Object's sophisticated pattern-matching and logical operators, which were used extensively in the process of search. The second component of the SDAS software framework is the Oracle DBMS, with a table within it recording the defect information communicated to it from the main SDAS program written in Nexpert. This database keeps track of defects occurring over the long term, and can be examined at any time for crucial information such as quality levels for different periods and operators.

The class-object hierarchies in the SDAS partition the knowledge base into carefully designed segments, each dealing with domain knowledge about the defect location, defect type and manufacturing operations and controlling knowledge pertaining to the status of the diagnosis and other details of the current defect. However, the task of searching within the structure of defect entities to arrive at the right decisions pertaining to the origin and causes of a defect, and the rendering of suitable remedial advice is shared by the control expressions in the rules of SDAS.

The reasoning method in SDAS is search. Three large groups of rules carry out the fundamental tasks of deduction of manufacturing operation, synthesizing appropriate extraction parameters to retrieve the diagnosis and furnishing the specifications relating to this defect. The first group of rules attempts to define the manufacturing operation responsible for the defect, from the location details supplied by the user. The second group of rules is based on the "Nature of Defect" class-object hierarchy, and is designed to perform the simultaneous tasks of synthesizing and retrieving the appropriate diagnosis, and to do some initial search processes for finding the relevant assembly specifications. The third set of rules finally defines the relevant set of construction norms and displays them if the user so wishes.

SDAS is smaller in size than FDAS. It has 70 rules, including the ancillary control rules (apart from the three main groups described above) and the rules for writing defect information to the database. There is a trade-off, however, in that the class-object hierarchy is complex. As in the case of FDAS, the elapsed time for each diagnosis cycle is about 15-20 seconds, depending on the complexity of the defect and the experience of the operator. It is believed that this short consultation time reduces the inspector’s effort in using the system and maximizes the time usefully spent on inspecting garments.

A graphics windowing interface based on the Open Look standards has been developed for the UNIX version of the SDAS program. Use of this interface simplifies the operation of SDAS and reduces the training required for inspection personnel. This interface uses the full complement of graphics facilities to present the user with a fast and easy way of classifying defects and obtaining diagnoses, without diverting too much time and attention from the primary task of inspecting garments. For the DOS version of SDAS, a Nexpert Forms character-based user interface has been developed.
SDAS has been designed to permit additions to the knowledge base. The diagnostics and remedial measures are stored in simple text files, which can be modified and added to with any text editor. However, SDAS itself is written in Nexpert, and suitable procedures must be followed to correctly manage any changes to the knowledge base.

2.10 Database Integration with FDAS and SDAS

On all four versions of the defect analysis systems (UNIX and DOS versions of FDAS and SDAS), the main defects analysis software written in Nexpert has been linked to a database. This interfacing of FDAS and SDAS with the respective database tables provides a way of recording defect occurrences in a systematic manner, while the defects analysis software sessions are in progress. The defects table(s) can then be cross-examined according to any selected group of query parameters to extract information relating to the extent of defects, their distribution within a period of time, major contributing factors, machine maintenance or setting problems. If a user desires to make modifications to the data written to the database, both the database schema and the structure of the rule triggering the write process have to be changed. The changes required in the rules are more difficult to make than the changes required in the database schema.

On UNIX, the communication with the database is completely controlled from the top-level graphical user interface, with full password prompting and the ability to selectively write to the database tables. In the DOS versions of these software systems, communication with the database is again transparent, but does not have certain features such as selective write. In this case, all the defect occurrences are recorded in the database.

The database interface is created using a database bridge, which is a special software that makes such program-to-database link easier. The database bridge has been used to write custom rules and database access procedures for controlling data transfer. Different copies of FDAS can be run on several UNIX machines at the same time, while recording defects data into one database via a network. This single, common repository of defects data collection from different inspection stations is ideally suited for a shop-floor inspection set-up. Similarly, the UNIX version of SDAS can be run in multiple sessions, communicating with a single database. However, due to an intrinsic lack of multi-tasking capabilities, the DOS versions of the analysis software cannot be easily made to work on a shared basis with a global database, without having to deal with complex DOS networking issues. Therefore, on a PC, FDAS will work with a single copy of Oracle loaded onto that machine. SDAS works in the same way.

2.11 Testing and Debugging

The development effort for the FDAS and SDAS software systems has been carried out exclusively on UNIX workstations, using a combination of Nexpert Object, C and the database software. This decision, during the early stages of the project, was driven by considerations of operating system power and sophistication, graphical user interface, etc. Because of the feature-rich programming environment, most of the testing and debugging has also been performed on these development machines.
FDAS went into a test cycle almost concurrently with software implementation. In addition, after the system was nearly complete, domain experts used actual defective fabric samples provided by commercial producers, to compare the system’s analysis with their analysis of the defects. This procedure helped iron out a number of errors in the system. Improvement in functionality was another important benefit; much of the enhancement to FDAS, to incorporate specialized defects contributed by new but popular manufacturing processes, arose from such testing.

FDAS was ported to the DOS computer with few problems. Special presentation scripts were created with the Nexpert Forms utility, for use in a simple yet effective user interface. These did not entail any modifications to the FDAS knowledge base, which remains virtually identical to its parent knowledge base on UNIX.

Much of the testing and refinement of SDAS has been similarly accomplished on UNIX. In this case, most of the testing has been done in-house. In part, this was due to the very well-structured knowledge accumulated from consultations with the apparel manufacturing experts at AMTC as well as the paper specifications used by the military.

Moving SDAS to DOS proved more difficult than moving FDAS. Several external programs, written in C, are being used outside SDAS to perform some important functions that cannot be carried out from within the knowledge base itself. These required a complete re-compile on the DOS system, and in some cases, re-working of the programs to fit within the constraints of DOS. However, the knowledge base itself did not change drastically.

The additional capability of interacting with the database was developed later, for all the versions of FDAS and SDAS. The task was carried out first for the UNIX versions of the software, and subsequently for the DOS versions. The researchers encountered some difficulties on this latter task, owing to errors in the software supplied by the manufacturer. However, these problems were eventually overcome and both FDAS and SDAS were integrated with Oracle on the DOS operating system.

### 2.12 Generalization and Recommendations

Two software systems have been created, each working on both UNIX and DOS machines. FDAS covers the domain of defects in conventional denim fabrics, up to and including the finishing stage. SDAS covers garment manufacturing defects (mainly assembly defects) in the process of making denim utility trousers. Both software systems have been tested and refined. Both systems are meant for in-process use, at the appropriate inspection stage. While the software has all the functional capabilities originally planned, and more, both systems could have benefited from more industrial cooperation (especially SDAS).

FDAS can be more easily generalized than SDAS. Defects in most other types of fabrics (other than fancy fabrics such as damasks or figured jacquards) are not very different from those that FDAS already treats. In fact, some special defects arising from specific and newer manufacturing technologies and relevant to the denim manufacturing domain of FDAS may not be often
encountered when dealing with other fabrics. The major classification criteria in FDAS are visual clues which are common across the range of fabrics. Therefore, extensions to FDAS will deal more with alterations to the diagnoses for the various range of defects, and less with expanding the range of defects. Since modifications to the diagnosis files are relatively easy, generalization and/or customizing of FDAS is simple.

As in the case of FDAS, the diagnostics information of SDAS is contained in text files. Hence, users can customize the system output to their requirements without affecting the working of the rest of the system. The directories containing the diagnosis files have been structured to exactly mimic the defects class structure. Hence, it is easy for the user to make modifications at the right place. On the other hand, making modifications to the knowledge base itself requires more knowledge engineering when compared to FDAS. The basis of classification, viz., nature of the defect and the location of the defect is applicable to all garment types. However, since the possible locations are different for different garment types, the defect class hierarchies will vary.
CHAPTER 3
PRELIMINARY INTERVIEWS AND INTERACTION WITH INDUSTRY AND GOVERNMENT

At the beginning of the research project, a major objective was to assemble a knowledge base for the analysis of defects arising at various stages in the manufacture of a utility trouser. Other objectives included establishing fruitful contacts with experts and interested personnel in the industry for obtaining input and advice on the design and development of the software, and identifying test-bed sites for the final testing of the software.

The major sources of knowledge on fabric and garment defects domain were:

1. The questionnaires sent to the industry, and
2. Interaction with experts in academia and the industry.

The third important means of accumulating domain knowledge was a thorough review of the research literature in the area of fabric and garment defects. This is separately described for FDAS in Chapter 4 and for SDAS in Chapter 7.

This chapter presents the design of the questionnaire, an analysis of the responses, and selection of domains for building the knowledge-based systems. An overall picture of cooperation with industry and other sources over the course of the project is also presented.

3.1 Development of Questionnaires

An exhaustive questionnaire (please see Appendix A), covering the technical aspects and detailed categorization of defects arising during the manufacture of utility trousers, was designed. This 'Defects Questionnaire' covers the entire range of defects arising in fabric and garment manufacture including trim defects. The questionnaire was refined on the basis of the input provided by members of the AMTC Steering Committee.

The objectives of this questionnaire were to:

1. Obtain a list of defects frequently encountered, and establish a categorization.
2. Determine the extent of defects arising from different sources.
3. Evaluate current quality control practices in the industry, and the training imparted to personnel responsible for defects analysis.

To obtain specific data on quality control practices, the respondents were asked to provide information on their test methods, statistical quality control procedures and tolerances allowed for individual property parameters. The bulk of questions pertained to individual defects in five major categories: fabric, thread, buttons, zippers and lining materials. Further queries sought details
about quality norms, inspector training and formal exposure to QC practices, and some statistics on the price penalty caused by the generation of defects.

Another, comparatively brief, questionnaire was also developed to get high-level input on the economic impact of defects. This 'Economic Impact' questionnaire (please see Appendix A) did not go into the technical details of defects; instead it attempted to get a larger picture of the economic impact of defects involving defect generation within each product grouping, price realization therefrom, and loss of productive time due to re-working. It also asked for an approximate estimate of the contribution of fabric and assembly defects to overall defect generation.

3.2 Analysis of the Two Questionnaires

About 550 questionnaires of each type were mailed to apparel companies, under the auspices of the AAMA. The companies included the whole range of organizational sizes and products (not just utility trousers). However, the rate of return was disappointing. Only about 35 Defect Questionnaires and about 25 Economic Questionnaires were returned. Of these, less than 40% were really useful. Three major disqualifying reasons were inadequate effort at providing all the answers, enormous ranges to the data supplied (making it virtually useless), and contradicting information at different places in the same response (rendering it unreliable).

However, from the useful responses to the questionnaires, an effort was made to glean as much information as possible. Important findings are shown in Table 3.1. The table shows that any reduction in fabric defects can bring about sizable savings to apparel manufacturers, since fabric defects form a significant proportion (often half or more) of total garment defects. Price realization for seconds varied between 20% and 75%, but in most cases it was close to 40-50%. There were only three companies using computerized defect tracking of any form. Almost none of the organizations that responded had any formal training procedures instituted for Quality Control Inspectors.

Almost all companies had quality norms for trim articles such as buttons and zippers, but relied on their suppliers conforming to this set of requirements and doing their own testing. While fabric specifications were extremely tight and defect levels generally higher for companies manufacturing high-quality women's underwear, fashionable sportswear, and men's or women's outerwear, they were more relaxed for utility garments. Seam pucker predominated the list of defects associated with delicate garments, but caused less value loss in the case of denim trousers.

3.3 Plant Trips and Industrial Visits

Initially, several trips were made to fabric and apparel manufacturing plants in Georgia and neighboring states. These trips were meant to gain some preliminary knowledge about the state-of-the-art in manufacturing techniques and production processes, quality inspection procedures, etc., and to discuss the project with the technical personnel.
Table 3.1 Summary of the Analysis of Responses to the Questionnaire

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of responses</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>% of Defective trousers</td>
<td>2</td>
<td>0.4-4</td>
</tr>
<tr>
<td>% Contribution of fabric defects</td>
<td>55</td>
<td>40-75</td>
</tr>
<tr>
<td>% Price realization for defective trousers</td>
<td>40</td>
<td>20-75</td>
</tr>
<tr>
<td>Annual sales (million $)</td>
<td>45</td>
<td>12-280</td>
</tr>
</tbody>
</table>

Computer assistance in quality control: Three of the 10 companies reported having computerized systems for collecting data on defects.

Training for Quality Inspectors: Most respondents did not have any formal training for quality inspectors.

Significant defects: 1. Shade variation in fabric
2. Missing warp threads
3. Filling defects
4. Soiled garments
5. Skipped stitches
6. Seam Puckering
These companies included denim fabric manufacturers such as Swift Textiles and Cone Mills, and apparel manufacturers such as Tennessee Apparel, Dowling Textiles, Levi Strauss, Oxford Slacks, Graniteville Industries and Coastal Industries. Some of the latter are general-purpose apparel manufacturers, but Coastal and Tennessee Apparel are almost exclusively defense contractors. In all these plants, the members of the research team got a good understanding of the production processes and the QC and inspection procedures.

Visits to Graniteville Industries, Swift Textiles and Cone Mills produced a wealth of information on denim fabric defects and inspection methods. They also provided an understanding of the commercial relationships between fabric suppliers and apparel makers, and the means used by the apparel manufacturer to provide feedback on defects seen in the fabric. The following general observations emerged from these visits:

1. The denim produced today predominantly comes from open-end spinning machines and air-jet weaving machines. These newer technologies have fewer, but very typical defects in their products, such as rotor yarn slubs, rotor piecings, etc.
2. Almost all the utility trouser manufacturers rely on the fabric supplier to inspect the fabric and to tag defects.
3. The spreading machine operator looks for these defect markers; there is no preliminary inspection at the apparel plant on the incoming fabric. There is usually no mechanism to provide feedback to the suppliers on consistently out-of-spec fabrics.
4. Most of the yarn indigo dyeing is of the ball-warp continuous range type.

An early visit to Tennessee Apparel was very useful in that it revealed the intricacies of some of the complex garments being manufactured for the military, and the special requirements of manufacturing apparel to meet military specifications. At Dowling and Oxford Slacks, the research personnel were exposed to other sectors of the commercial apparel market, such as the manufacture of hospital apparel and men’s dress slacks, respectively.

Interaction with fabric procurement experts from Levi Strauss gave a good understanding of the typical fabric specifications and the sampling and testing practices followed by a large garment manufacturer. Meetings with the QC chiefs of Levi Strauss’ main garment manufacturing facilities in Tennessee gave the research team an appreciation for the assembly sequences, inspection schemes, defects analysis and control being used by the company in the domain of utility trousers. All these details were noted and subsequently reviewed when drawing up the defect classification schemes and software design, so that the developed system would be compatible with the systems currently functioning in the apparel industry.

The last major plant visit was to Coastal Industries, a large military contractor in Selma, Alabama. The fruitful interaction with the management staff and top QC employees resulted in very useful guidelines for directing the software design and classification scheme for SDAS.
CHAPTER 4

FABRIC DEFECTS: KNOWLEDGE ACQUISITION

Knowledge acquisition is a critical step in the development of knowledge based systems. The task here has been to acquire as much knowledge about defects in fabric manufacturing from as many sources as possible, and to collate this information to realize the most comprehensive assembly of facts and relationships concerning defects, their occurrence, causes, and remedies. This chapter describes the knowledge acquisition process.

Another aim during this phase of the research has been to refine the research objectives, and to accurately define the specifications of the software system. Factors considered in the refinement process are possible applications, user profiles, further extensibility and response time requirements.

4.1 Sources of Knowledge on Fabric Defects

Several books and research publications contributed to the store of information on fabric defects. The major references and the areas covered by them are summarized in Table 4.1. Most fabric defects are found by visually inspecting the fabric for distinguishing features of a defect and by identifying the defect according to these characteristics.

The primary reference has been the work of Thomas [Thom 87]. This experienced Sulzer-Ruti engineer compiled a list of defects in grey fabrics which included probable causes and appropriate remedial actions. The compilation of the current knowledge base was begun with Thomas’ work as the primary source. It was also used as the basis for identifying key characteristics of defects appropriate for classification. Based on other sources, the list of grey fabrics was made more complete, defects caused during chemical processing were added, and the earlier scheme of classification was refined. The lists of defects obtained from the questionnaires were used to verify the completeness of the compiled list with respect to fabric defects.

Several other books were used to add to and enhance the knowledge base accumulated by Thomas. Patel [Pate 74] discusses 235 fabric defects and their possible causes. In many instances photographs of defects supplement the defect descriptions. The issue of motivating personnel towards better quality control is also discussed. Hesse [Hess 52] has described the causes of fabric defects and loom stops in his work. An alphabetical listing of the defects along with photographs and explanation of the origin of some of the defects has been published by Hauptverband Baumwollweberei [Haup 63]. The German approach was also used in the Manual of Standard Fabric Defects in the Textile Industry compiled by the Graniteville Company [Gran 75], a major reference in the field. Fabric Inspection and Grading by Powderly [Powd 87] discusses different systems for fabric grading, quality specifications of both corporate and government institutions, and has an alphabetical list of defect definitions with some photographs. Grover and Hamby [Grov 60] provide an alphabetical list of fabric defects with textual descriptions. ASTM D 3990-85 [ASTM 85] includes the standard names for the defects, various synonyms, causes of the defects and some
Table 4.1 Major References For Fabric Defects

<table>
<thead>
<tr>
<th>Reference</th>
<th>Fiber Yarn</th>
<th>Greige Fabric Finished Fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Thom 87]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>[Pate 74]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>[Gold 57]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>[Gran 75]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>[Gard 83]</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>[Pali 83]</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>[Ratn 84]</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
photographs. Government sources of information for textile defect analysis include the specifications developed by the military procurement divisions [MIL 84]. The MIL Specs are different from other literature in that they specify the standards and the tolerances for the materials and construction parameters. Many individual companies also have their own defect lists, defect descriptions and guidelines for grading and acceptability norms.

Several research papers and technical publications also provided more specialized insight into some defects on the list. Foster [Fost 52], Mahajan [Maha 86], and Balasubramanian and Sekar [Bala 82] have discussed the problem of filling streaks and diamond patterning defects in filling. The publications of South India Textile Research Association, and Ahmedabad Textile Industries Research Association give norms for quality and are good reference sources for the correct choice of process parameters [Ratn 88, Pali 83, Gard 83]. They also discuss the defects caused by incorrect parameters in spinning and weaving.

Table 4.2 shows the final list which consisted of 85 defects.

4.2 Fabric Defects: Occurrence and Causes

The literature reviewed on defects either just lists the defects alphabetically or classifies them according to the origin of the defect. Thus, most of the literature used either the manufacturing process causing the defect, or the severity of the defect as the basis of classification of defects. This is a serious shortcoming if one wants to refer to these sources to find the exact nature of a defect and to identify its origin, because the basic structure of knowledge in these sources presupposes precise knowledge of the particular defect under investigation.

An alternate way of classifying the defects in the textile materials is to base identification and analysis of a defect upon its visual characteristics. Also, there are other requirements of such a classification scheme: it should be hierarchically arranged to minimize the search process, and should be general enough to accommodate new defect descriptions added at a later date. A description of a necessary and sufficient set of these visual attributes of defects is introduced in the next chapter as a conceptual basis for representing the classification of fabric defects.

The same defect can occur in several ways on the fabric, owing to technological reasons. For example, a single bobbin of coarse yarn will result in a thin, single warp-wise streak running along the length of the fabric. If that bobbin is in the filling, the coarse yarn will manifest itself as a rectangular bar across the fabric. Because of this possibility of multiple modes of occurrence, a thorough technological analysis has been carried out for each of the 85 fabric defects, with a goal of achieving a complete map of every conceivable manifestation.

In the same vein, there may be more than one technological reason for a defect to occur in a certain manner. Depending on the mode of occurrence, every defect was fully investigated as to the possible human/machine/process/random causes which could contribute to its incidence. In every case where a defect has multiple causes, all of the possible causes are listed in the diagnosis file pertaining to that fabric defect. Each defect has its own diagnosis file, comprising a set of probable causes, and a listing of suggested remedies.
<table>
<thead>
<tr>
<th><strong>Point Defects</strong></th>
<th><strong>Line Defects</strong></th>
<th><strong>Area Defects</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Burnt hole</td>
<td>1. Abrasion</td>
<td>1. Abrasion</td>
</tr>
<tr>
<td>2. Cockled yarn</td>
<td>2. Broken end</td>
<td>2. Apron mark</td>
</tr>
<tr>
<td>5. Gout</td>
<td>5. Corded selvage</td>
<td>5. Break out</td>
</tr>
<tr>
<td>10. Large knots</td>
<td>10. End out</td>
<td>10. Filling bar</td>
</tr>
<tr>
<td></td>
<td>15. Kinky yarn</td>
<td>15. Mat-up</td>
</tr>
<tr>
<td></td>
<td>16. Looping pick</td>
<td>16. Oil stain</td>
</tr>
<tr>
<td></td>
<td>17. Misdraw</td>
<td>17. Pucker fabric</td>
</tr>
<tr>
<td></td>
<td>18. Missing pick</td>
<td>18. Reediness</td>
</tr>
<tr>
<td></td>
<td>20. Mixed yarn - Twist</td>
<td>20. Rust stain</td>
</tr>
<tr>
<td></td>
<td>22. Reed mark</td>
<td>22. Shade variation - fabric</td>
</tr>
<tr>
<td></td>
<td>23. Rotary yarn piecing</td>
<td>23. Shade variation - yarn</td>
</tr>
<tr>
<td></td>
<td>24. Rotary Yarn slubs</td>
<td>24. Shrink mark</td>
</tr>
<tr>
<td></td>
<td>25. Seam mark</td>
<td>25. Shuttle smash</td>
</tr>
<tr>
<td></td>
<td>27. Slack end</td>
<td>27. Specky dyeing</td>
</tr>
<tr>
<td></td>
<td>29. Tight end</td>
<td>29. Tender spot</td>
</tr>
<tr>
<td></td>
<td>30. Tight pick</td>
<td>30. Thick place</td>
</tr>
<tr>
<td></td>
<td>31. Uneven yarn</td>
<td>31. Thin place</td>
</tr>
<tr>
<td></td>
<td>32. Warp burl</td>
<td>32. Torn cloth</td>
</tr>
<tr>
<td></td>
<td>33. Warp streak</td>
<td>33. Uneven fabric width</td>
</tr>
<tr>
<td></td>
<td>34. Yarn shade variation</td>
<td>34. Uneven finish</td>
</tr>
<tr>
<td></td>
<td>35. Yarn slubs</td>
<td>35. Uneven yarn</td>
</tr>
<tr>
<td></td>
<td>36. Waste in filling</td>
<td>36. Variable selvage dyeing</td>
</tr>
<tr>
<td></td>
<td>(on loom)</td>
<td>37. Wavy fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>38. Wavy selvage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39. Wrong pattern</td>
</tr>
</tbody>
</table>

Table 4.2  List of Fabric Defects in FDAS
4.3 Literature Review: Computers in Other Interpretation and Diagnosis Tasks

The literature reviewed in this section will focus on aspects such as the stages in the development of a KBS, the decisions to be made at each stage and the criteria for making these decisions. Diagnosis systems from other fields will be used to illustrate the various points. The text by Waterman [Wate 86] provides a good introduction to the concepts and methods involved in building KBS.

Waterman provides guidelines to determine the appropriateness, feasibility, and justification for building a KBS for a specific problem. Slagle and Wick [Slag 88] also describe an analytical method of evaluating an application area. They propose a list of domain features, classified as essential and desirable features. These features are to be assigned weights and the chosen domain is to be assigned scores for each feature. The candidate domain will be assigned an overall value on a 0-10 scale. They recommend a spreadsheet model to evaluate different domains.

The domain is then subject to careful analysis, to identify the main characteristics and special problems that will have a bearing on the decisions to be made at a later stage. Stefik et al. [Stef 83] have proposed a framework to characterize any problem in terms of complexity arising due to the size of the solution space, lack of certainty and stability of data, and lack of certainty of knowledge. They discuss 11 cases in increasing order of complexity and the techniques adopted to deal with each case. The techniques recommended to deal with a large solution space, such as hierarchical partitioning of the solution space and generate and test have been used in different systems to give a robust performance by minimizing the search [Laff 84, Thom 83]. The validity of the methods to deal with uncertainty is yet to be sufficiently established. Szolovits and Pauker [Szlo 78] have made some observations about the "extreme reluctance" on the part of both "experienced and novice physicians" towards "any formal computation of likelihoods." Quinlan [Quin 83] discusses the pros and cons of different methods to deal with uncertainty.

Most of the diagnosis systems serve as consultants to a human expert when needed, and are especially useful when the time taken by the system to come to a conclusion is not a serious constraint. Some systems, however, are used for tasks in which time is critical. Masui and McDermott [Masu 83] have developed AIRPLAN, which is a system for recommending launching and recovery of aircraft from a carrier after interpreting data about the current situation. They have discussed how consideration of the criticality of time affected their design decisions at different stages.

The next focus is on conceptualization, a phase wherein the activities of identifying the key concepts, relations, and specifying strategies and constraints related to the problem-solving activity, are performed. As an example, Kahn and McDermott [Kahn 84] identify approximately 20 key properties of mud such as density, viscosity and solid content during the conceptualization phase of their drilling fluid diagnostic system. The data that indicates whether any of these properties have values higher or lower than normal are used to determine the cause of the problem. Aikins [Aik 83], in her system for diagnosis of pulmonary diseases, classifies diseases at the top level according to their effect as constrictive, restrictive, diffusive, etc. These classes are in turn categorized according to their severity into four subclasses.
Structures for organizing knowledge or concepts are now designed in the formalization stage. According to Waterman, this involves mapping the key concepts identified in the conceptualization phase into a formal representation. The two important decisions to be made here are the paradigm to be used for representing the domain knowledge and the inference mechanism to be used for manipulating the knowledge to solve the problem. Aikins gives the following criteria for both these decisions:

1. The chosen method of knowledge representation should explicitly show the function of every piece of information - whether it is knowledge about the domain or control knowledge.
2. The domain knowledge should be separate and should be easily manipulated by the inference mechanism rather than being built into it.
3. It must be easy to add or remove knowledge about the domain.
4. Multiple uses of the knowledge base must be possible.
5. The part suggesting the remedies must be separate from the diagnosis segment.

The two major methods of knowledge representation identified by Waterman are rule-based representation and frame-based representation. He includes both frames and semantic nets under frame-based representation. Minsky [Mins 75], who originated the frame idea describes it as a data structure representing a stereotyped situation with several kinds of information attached to each frame. Waterman's description of a frame closely corresponds to how it is implemented in practice: "a knowledge representation method that associates features with nodes representing concepts and objects. The features are described in terms of attributes (called slots) and their values." Many of the early systems, e.g., MYCIN [Shor 75], DENDRAL [Buch 78], ACE [Veso 83] and REACTOR [Nels 82], use rule-based reasoning; PIP [Kuli 80], and NUDGE [Gold 77] use frames; PROSPECTOR [Duda 84], GLAUCOMA [Szol 78], AM [Lena 76], and CENTAUR [Aiki 83] are systems that use a combination of rules and frames.

Aikins has summarized the strengths and weaknesses of frames and rules as representational paradigms. According to her, frames are suitable for knowledge representation when there are standard data patterns with a preenumerated range of plausible data values i.e., the conceptual entities in the domain can be described in terms of predefined frameworks of attributes and there is only a finite number of possible descriptors for each of the attributes. The main advantages of rules, according to Aikins, are uniformity and modularity. However, these advantages themselves can give rise to certain difficulties. Due to the uniform method of representation, the function of the rule is not explicit. Because of modularity, the indirect impact of adding or deleting a rule is not apparent. These and other disadvantages of rules can be overcome by the use of frames. A few other deficiencies in early rule-based systems have been overcome in recent systems. For example, Aikins mentions that in rule-based systems there is no control over the order in which the system will question the user. Most of the rule-based tools have an implicit control depending on the order in which the data is arranged in the rule. Nexpert Object, a KBS shell from Neuron Data, allows explicit control by assigning priority numbers to objects.

After the problem domain has been adequately and accurately represented by corresponding information structures, the task of using this representation to achieve a meaningful end is accomplished using some type of inference process. Problem solving tasks have been described dif-
ferently as search [Fike 80], reasoning [McC 69], or constraint satisfaction [Fox 84]. Most di‐
agnostic tasks, particularly in medicine, have been characterized as search. Systems that interpret
the behavior of mechanical or electronic systems have been described as reasoning systems. Plan‐
ing systems are described in terms of the constraint satisfaction metaphor. Simon [Simo 83]
points out that all the three metaphors are simply different views of the same problem solving al‐
gorithm. Hence, the only clear distinction among problem solving methods seems to be based on
the nature of knowledge employed by them - whether it is based on cause-effect relationships or
just an associational model of related components of the system.

Associational models have been described as shallow, surface, compiled, or low-road, and
causal models as deep, model-based, or high-road. Clancey [Clan 85] describes associational or
heuristic knowledge as follows:

A heuristic relation is uncertain, based on typicality, and is some‐
times just a poorly understood correlation. A heuristic is often empirical, derived from problem solving experience. Heuristics of
this type reduce search by skipping over intermediate relations ...
Intermediate relations may be omitted because they are unobservable or poorly understood.

The advantage of using associational knowledge which embodies the precompiled knowledge of
the expert, in terms of speed and efficiency has been pointed out by Genesereth [Gene 84] and Fink,
Lusth, and Duran [Fink 85]. It is also more modular as relationships between system components
are not deep. It is the only option available when the human understanding of the domain is limited
[Gene 84]. Bublin and Kashyap [Bubl 88] and others advocate causal model mainly for two rea‐
sons - their ability to handle novel situations obviates the need to preenumerate all possible system
states, and they can offer a better explanation of their line of reasoning based on their deeper
knowledge of the domain. There are certain serious handicaps to the causal models, e.g., the com‐
piled knowledge of the expert cannot be embodied in them, and so they cannot employ shortcuts
even for very common problems. Some systems such as IDT [Shub 82], IN-ATE [Cant 83] and
GLAUCOMA [Szlo 78], use a combination of both model-based deeper reasoning and rule-based
heuristic reasoning in their problem solving.

After establishing the most reasonable metaphors for representing the knowledge, specific
mechanisms for problem solving have to be identified. Stefik et al. [Stef 83] offer guidelines for
selecting a method of search depending on the domain characteristics identified. Several research‐
eers have reported employing different techniques such as generate and test [Laff 84], resolution
theorem proving [Gene 84], belief updation by minimaxing [Cant 83] and simulation [Benn 84].
Hierarchical classification of the hypotheses to make search more efficient is common in medical
diagnosis systems [Thom 83, Szlo 78]. Here, category hypotheses describe groups of diseases that
have some common features, the disease hypotheses describe individual diseases, and pathophys‐
iological hypotheses describe the faults in the system causing the disease.

As far as implementation issues are concerned, there are a variety of software and hardware
platforms available for implementing a knowledge-based system (KBS) for diagnosis. General
purpose languages such as LISP have the advantage of flexibility when compared to special pur‐
pose tools. On the other hand, special purpose tools built specifically for developing KBS enhance
the productivity of the knowledge engineer by several orders of magnitude. These tools are be-
coming less expensive, impose very few limitations on the knowledge engineer in knowledge representation, provide user-friendly interfaces, can communicate with or can be embedded into conventional software, and are increasingly available on a wide variety of personal computers and workstations. Freedman [Free 87] has evaluated 27 KBS building tools in terms of their main features. The features have been classified into syntax, semantic and pragmatic features and a summary of the evaluation is presented in three matrices. Gevarter [Geva 87] has developed a framework for classifying the attributes of a KBS building tool in terms of developer and user interface and compatibility with other software. He has also evaluated several of the available tools using the framework developed. The methodology developed by these authors is very useful, since KBS tools are being continuously upgraded and new tools are entering the market rapidly.

4.4 Literature Review: Human-Computer Interface

A friendly and easy-to-use interface is as important as completeness and accuracy of the system. The interface requirements for a system developer are different from the requirements for an end-user of the system. Many KBS building tools provide the programmer with a wide range of features to enable rapid development of the system. However, the same plethora of tools may clutter up the interface for the end-user and obscure the features essentially required for the utilization of the system. Hence, developers of a software system should consider the user profile and customize the user interface to meet the requirements and abilities of the user. Literature in the areas of design of menus, dialogue and output windows, and constructive error messages are presently reviewed.

Shneiderman [Shne 86] identifies the following seven as the key issues in practical implementation of human-computer interface:

1. Interaction style
2. Input techniques
3. Response Time
4. Output Organization
5. Error handling
6. Individual differences

The relevance of these issues to the design of the user interface for FDAS is discussed in Chapter 4.

Menus are a popular means for selecting options/commands. This is because of several advantages: minimal learning effort, very little or no typing required, and structured decision making [Shne 87]. There are, of course, a few limitations, such as a need for a rapid response rate, screen space requirements and possible need to display a sequence of menus. Hierarchical menu displays overcome some of these objections. Several colors and large screen displays reduce user fatigue. Buttoned prompts, different cursor shapes/sizes, and blocking inputs serve to direct and guide the user about appropriate responses throughout an application.

Smith and Mosier [Smit 84] offer five high-level objectives for any form of data entry:

1. Consistency of data entry transactions
Extensive research has been carried out to identify factors that are critical for achieving the above objectives and, wherever possible, to quantify the effect of varying the factors. Researchers have found that semantically meaningful organization of items within a menu helps to reduce user errors considerably, compared to alphabetical organization [Lieb 82, McDo 83, Lee 80, McEw 81]. Shneiderman [Shne 87] emphasizes the need for using terms whose meanings are clear to the user. With the hierarchical breakdown of items into menus, the user is faced with the trade-off between width and depth, i.e., between the number of items to be displayed in a menu, and the number of levels of menus. Miller [Mill 81] chose 64 items that could be fitted into valid semantic hierarchies. Of the four different width-depth combinations tried, the lowest error rate occurred with eight items per menu. There is general agreement that 4 to 8 items per menu, with no more than 3 or 4 levels of menus is ideal for minimizing user errors. Miller’s classic paper on short-term memory emphasizes the need for keeping the items for consideration at any time within the "magical seven plus or minus two" to maximize the information processing rate, and to minimize error.

Besides an hierarchical layout of the display, a rapid display rate is also an absolute necessity for avoiding user annoyance with menu-based dialogue systems. Miller [Mill 68] has found that on most tasks, users are willing to wait up to two seconds for a response without loss of patience. But on certain tasks, it was found that the user’s expectation of the response time was as low as one tenth of a second. This is especially true for users who have some familiarity with the software, and this would be achieved by FDAS’ users in a matter of days. Since FDAS’ response is critical for the completion of a task and the user is to be paid on the basis of the amount of task accomplished, the user is not likely to tolerate any delay in system responsiveness.

Similar to the objectives for data input, there are quality criteria for the output of an interactive software system. Well-formatted output is critical for the user to derive maximum benefit from interactions with the system. As with the design of input windows, the task and user requirements are to be well understood for designing good output formats. Smith and Mosier [Smit 84] suggest 162 guidelines for the design of effective output information structures. Tullis has shown that data in structured format can be comprehended more easily than data in narrative form [Tull 81]. Consistent positioning of the output has been shown to improve comprehension and retention of data presented in the output [Teit 83]. Color graphics display has been shown to evoke positive reactions in the user, though the performance did not improve significantly [Tull 81]. If carefully planned, colors can be used to show important concepts such as status changes and different categories of items such as queries and messages. However, if not used conservatively, color may impede comprehension of data in the output.

Error display and handling is another critical area of human-computer interface design. Users commit errors while using a software system because of lack of knowledge or inadvertent slips, which are to be expected especially at the novice stage. Too generic or obscure error messages will be of no help to the user and may leave the user feeling frustrated or inadequate. Golden [Gold 80] and Dwyer [Dwye 81a, 81b] have proposed general guidelines for more helpful error
messages. To generate more specific error messages, very careful planning of input parsing stra-
tegies, and message generation strategies is required. Because of these requirements, the objectives in this area are difficult to achieve. Specificity, positive tone, user-centered phrasing, and appropriate physical format are the general guidelines given by Shneiderman [Shne 87] for designing appropriate responses to user errors.

A well-designed user interface should also be able to partially adjust its modes of functioning, verbosity of output and contextual help features to conform to the standards and abilities of the user. This is usually somewhat difficult to achieve without a self-assessment on the part of the user, before the actual software commences its operation.
CHAPTER 5

FABRIC DEFECTS: REPRESENTATION AND REASONING

The design of the conceptual representation and its formal mapping into software constructs are covered in this chapter. The fundamental visual features used to identify and classify a defect are described. Following this, the procedures involved in the analysis and diagnosis of fabric defects using this software are discussed. Specific implementation issues are treated in the next chapter.

5.1 Classification Scheme

A woven fabric is a planar assembly with a finite width and a nominally infinite length. In case of the fabric having some flaw or imperfection, it (the defect) is likely to have a certain orientation and extent. Fabric defects can be classified on the basis of the following attributes:

1. Type of defect;
2. Direction and Extent of defect (with respect to the fabric);
3. Repeating Pattern of the defect along the two principal fabric directions (length & width);
4. Appearance of defect;
5. Size of defect;
6. Location of defect.

The descriptors used to characterize each of the defects according to these characteristics were listed. Some defect characteristics, such as Type, Direction, and Pattern had only a limited number of possible descriptors. These 'key' characteristics and their possible descriptors are shown in Figure 5.1. Appearance had almost as many descriptors as the number of defects. These three were the primary attributes forming the current defect classification and identification scheme.

The Location of the defect was found to be useful only for separating selvage defects from the rest of the defects. The Size of the defect was used only in some instances to characterize the defects. Therefore, these characteristics were not included in the list of key characteristics finally adopted for the system; on occasion, their descriptors were incorporated into the accepted visual attributes given above.

The defect characteristics with limited number of possible descriptors i.e., Type, Direction, Lengthwise and Widthwise patterns, were used to classify the defects into broad categories. For example, the Type defect characteristic has three descriptors: Point, Line and Area. Similarly, the Direction characteristic has five descriptors: Continuously Along the Length, Partially Along the Length, Continuously Across the Width, Partially Across the Width, and No Preferred Orientation. The intersection sets of all these categories divide the whole set of fabric defects into smaller subsets. Figure 5.2 shows the classification of area defects using the additional visual characteristics.
Figure 5.1. Schema of Garment Defect Classification
Direction, and Length and Widthwise Patterns. The other two subclasses based on Type, i.e., Line
and Area defects are also broken down in a similar hierarchical fashion.

The nomenclature of the defect subclasses that is being used is shown in the box at the top
of Figure 5.2, which is a pictorial representation of all the intersection sets of the classification cat­
ergories. The acronyms used and their expansions are shown to the left of the figure. The general
format of the subclass names is ZZ[Z]-WX[X]FY[Y]. ZZ[Z] represents the direction of defect
with a two or three lettered acronym. The second part of the name, i.e., WX[X]FY[Y], represents
the lengthwise and widthwise patterns of the defect, respectively. W (for warp) and F (for filling)
indicate lengthwise and widthwise pattern of the defect, respectively. X[X] and Y[Y] represent
the widthwise and lengthwise patterns with one or two lettered acronyms. For example, the class
name NPO_WIFR, stands for defects with No Preferred Orientation (ZZ[Z]), whose lengthwise
pattern is Isolated (WX[X]), and widthwise pattern is Random (FY[Y]) (See Figure 5.3).

For illustration purposes, the classes corresponding to defects with no preferred orientation
(NPO) are "sliced off" from the other classes in Figure 5.2. Figure 5.3 takes this slice and expands
to show more detail; all the NPO classes and the individual defects in two classes viz., NPO_WIFR
and NPO_WReFI, are shown. Whenever the number of defects contained in a subset was more
than eight, as in NPO_WIFR, it was further divided using additional discriminating criteria such
as the Size of the defect or other appropriate characteristics. Ultimately, the Appearance of the de­
fect, which is unique to each element in a subset, was used to identify the defect uniquely.

The proposed scheme marks a departure from the traditional methods of classifying fabric
defects as warp and filling defects or as spinning and weaving defects. The traditional methods
presuppose knowledge of the exact identity of the defect and its origin, whereas this is precisely
the information sought by a user from a defects analysis system. The scheme of classification in
FDAS depends only on the visual attributes of fabric defects, which would be input by the user.
The identity of the defect, its probable causes and remedies will be in the output of the system
(FDAS).

5.2 Analysis of Defects: Diagnosis

During the formalization stage, the key concepts identified during conceptualization are
mapped to paradigms for software implementation. The basic nature of the model chosen for
FDAS is the associational type. Such a model would be fast and will have an advantage in mod­
ularity over a causal model, which requires building a model of the domain in software with all
relationships between entities and components fully explored. An associational model for diagno­
sis requires pre-enumerative description of all possible defects in software, with search and appro­
priate selection during a diagnosis process. While this is inefficient, it is the only alternative
because there are two major problems with building a ‘deep’ causal model:

1. Causal relationships between entities in the domain of fabric defects are not clearly established;
   this is a prerequisite for building a pure causal model.
2. The different operations up to and including garment manufacturing viz., spinning, weaving,
   wet processing, and sewing are typically carried out at different locations and by different orga-
Figure 5.2 Classification of Fabric Defects According to Key Characteristics
NPO_WIFR
- Stains/shade variation
  Beam/fabric contamination
  Oil stains
  Rust stains
  Tender fabric
  Soiled fabric
  Shade variation in fabric dyeing
  Specky dyeing
  Size patches
- Holes/torn fabric
  Burnt holes
  Torn fabric
  Holes (Chemicals)
- Knots/stretched warp yarns
  Break out
  Hard size
  Mat up
  Size patches
- Others
  Abrasion-fabric mishandling
  Size patches
  Tender fabric
  Shrink marks

Figure 5.3 Further Categorization of Classes with more than Eight Defects
nizations. Consequently, all process parameters may not be available to a single user.

A hybrid formal representation is chosen for representing the entities in this domain, comprising *class-object hierarchies* and *rules*. Since the entities in the domain knowledge are hierarchically classifiable, it is possible to represent them using classes and objects. The use of class hierarchies has several advantages. The class hierarchies make the knowledge in FDAS highly structured. The relationship between different entities in the knowledge base becomes explicit. The part of the rule base using the entity descriptions for actual inferencing, and the part controlling the inferencing process are made clearly distinguishable by the use of two distinct class hierarchies.

The use of rules to represent domain knowledge helps in meeting certain important system requirements. The *if-then rules* are easier to understand than the other reasoning models and yield a more compact knowledge base. Due to uniform representation of knowledge, the modularity of the knowledge base is maintained. Hence in FDAS, the domain entities such as Bad Knots are represented using objects, types of entities such as Line Defects are represented as classes and rules are used for reasoning.

The number of defects in the current version of the knowledge base is 85. Since a defect can occur in several different modes (see Figure 5.4), there are more than 350 solutions to be considered. For dealing with large solution spaces, Stefik [Stef 83] suggests hierarchical classification of the hypotheses space as the first strategy to be tried. The entities in the current domain are *hierarchically classifiable*, and have common characteristics. Therefore, a process of searching through classes of defects by matching user descriptions with the class attributes, and pruning classes of defects early during the search, was chosen.

Some defects may belong to more than one class. For example, a coarse yarn will appear as a line defect if it is in the warp direction whereas it will appear as an area defect in the filling direction. *Multiple inheritance* allows any object to be an instance of more than one class, and inherit the properties of all the "parent" classes. Hierarchy of classes, with multiple inheritance, was chosen as the method of representing different categories of defects in FDAS [Srin 90].

### 5.3 Selection of KBS Software Tools

Once the key concepts in the domain and the paradigms best suited to represent them have been identified, they have to be implemented on a computer for practical use. Prior to system development, the software tool best suited for implementation must be selected. The different considerations which guided the tool selection are discussed here.

The first decision to be made is whether a general purpose language or a special purpose KBS tool is to be used for implementing the system. Once this decision is made, the specific language or the tool can be chosen. This is an important decision as the performance and the cost of the system will depend to a great extent on the chosen tool. The task and the domain requirements enumerated in Chapters 3 and 4 have to be matched with the capabilities of the tools in making a choice.
Figure 5.4  Different modes in which a Coarse Yarn Defect can occur in a fabric
Languages used for AI applications, such as LISP, are continuously enhanced through object-oriented representation, through their own programming environments such as multiple windows, and offer the advantage of flexibility in terms of system design. On the other hand, elements such as the inference engine, database interfaces and easy-to-use development environment have to be programmed anew, at least once, when a language is used. Features such as these are readily available in most of the commercial KBS building tools. This allows the system designer to concentrate on knowledge acquisition and representation, reducing the time required for system development. In other words, the system designer can think at the higher conceptual level of domain entities and relationships to be represented, than at the lower level of representational medium. Some KBS building tools provide the user with a rule-specific or object-specific editor, which makes it possible for the user to add to the knowledge base easily. For any system expected to be used by a large number of users, especially those without proficiency in programming, such easy modifiability is essential. These tools are increasingly available on a wide variety of computers, and some of them allow the same knowledge base to be used across different computers. Hence, using a KBS building tool for system development reduces the development efforts and the time required. Considering the above factors, it was decided to use a KBS building tool for developing FDAS.

Several commercially available tools for the development and use of KBS applications run only on personal computers, and support relatively small knowledge bases. Since the chosen task requires relatively large amounts of knowledge about different materials and processes involved in the manufacture of fabric and apparel, only more powerful tools, capable of supporting knowledge bases with 1000 rules or more without loss of robustness were considered. The chosen method of representing different categories of defects was class hierarchies with multiple inheritance. Therefore, it was essential that the chosen tool provides for object-oriented representation. ART [ART], KEE [KEE], Knowledge Craft [Know], Nexpert Object [Nexp], PICON [Pico], and ESP Frame Engine [ESP], support object-oriented representation well. Personal Consultant+ [PC+], S.l [S.l], and KDS [KDS] are other tools that support object-oriented representation without some features such as selective inheritance or demons.

Since FDAS is intended for wide use in the textile/apparel industry, it should work on as wide a range of machines as possible. Compatibility with already available machines will make the system more readily acceptable to the user. ART, KEE, Knowledge Craft, Nexpert Object, Personal Consultant+, and S.1 are the only tools, among those mentioned above, meeting this requirement. Of these, only Nexpert Object and Personal Consultant+ have run time versions requiring fewer than 640 KB of memory, the current RAM accessibility limit imposed by MS-DOS.

Mettrey [Mett 87] observed that "the use of object-oriented programming in the environment provided by ART, KEE, and Knowledge Craft requires proficiency in LISP in order to develop the required methods." Although rich representational methods are required, a user without much programming knowledge should be able to implement them. Creating and modifying objects in Nexpert Object requires some learning, but does not require any proficiency in programming. Similarly, it is easier to tailor FDAS for working with other types of software if it is based on a common language such as C. KEE and ART are LISP-based shells; it is difficult to find good LISP programmers when compared to finding programmers conversant in a traditional language such as C or Pascal.
Another very important factor is price. Nexpert Object costs from half to a fourth of the cost of environments such as ART and KEE. All these factors favored the selection of Nexpert Object. Other advantages of this software tool for building KBS are facilities for rapid prototyping (such as incremental compilation), simple links to relational databases such as Oracle or dBaseIV and hypertext tools, consistency maintenance between different editors, etc. A KBS built using Nexpert Object can call an external program or can be called from an external program; this kind of total integration with other software is absolutely essential, since a defect analysis system need not be a stand-alone system in a manufacturing enterprise. Text files, graphical files and scanned raster files can be displayed at any point during a session, using a simple "Show" command. This feature may be very useful for future versions of FDAS, in which textual descriptions of the defects can be replaced by pictures. Knowledge bases are portable across several supporting hardware platforms, which makes it possible to do the development work on a powerful Unix workstation, and makes the same knowledge base available on common computers such as IBM PCs and Macintosches.

The inference engine built into Nexpert Object uses an efficient "opportunistic search", employing a combination of data-driven and goal-driven approaches. This is possible because the same set of rules can be used both in forward chaining and backward chaining modes without any modification. This enables the user to describe an unidentified defect, based on its visual attributes and let the FDAS determine what the defect could be (forward chaining). This type of usage is the primary functional mode for FDAS. Alternatively, the user could suggest a defect to FDAS and let it find out if the defect is present (backward chaining). However, this type of reasoning is not used because FDAS' typical usage is in the opposite direction: a diagnosis session is triggered by the user only when an unknown defect is seen and classification/diagnosis is desired.
CHAPTER 6

FABRIC DEFECTS: SOFTWARE IMPLEMENTATION OF ANALYSIS FRAMEWORK

This chapter presents the details of the software development of FDAS based on the knowledge representation and the reasoning processes. In FDAS, the domain knowledge is represented using a hierarchy of classes and objects, and reasoning is implemented using rules. The implementation of the class hierarchies and rules is explained and illustrated with three test cases.

6.1 Class-Object Representation

The broad conceptual classification of fabric defects, with the primary visual attributes of the defects shown as sub-classes was discussed in Chapter 5 (Figure 5.1). Some changes and additions to this conceptual class hierarchy were made during the implementation of FDAS. To separate domain knowledge and control knowledge, two separate class hierarchies are used in FDAS, one for representing fabric defects and another for controlling the focus of the search process.

Figure 6.1 shows the highest level classes of the two hierarchies; Figures 6.2a and 6.2b show parts of the two class hierarchies and illustrate their structures. Circles represent classes, squares represent slots or properties of the classes, and triangles indicate the objects or instances of the classes. The filled squares indicate properties with ‘meta-slot modifications’. These meta-slot modifications are basically property modifiers, and can be used for specifying initial values or for invoking demons for performing actions such as changing inheritance dynamically. Another valuable application of a meta-slot modification is to override the Nexpert Object default query about any object ("what is the value of ...") and make it more specific and meaningful.

Figure 6.1 shows the highest level classes of the two hierarchies; Figures 6.2a and 6.2b show parts of the two class hierarchies and illustrate their structures. Circles represent classes, squares represent slots or properties of the classes, and triangles indicate the objects or instances of the classes. The filled squares indicate properties with ‘meta-slot modifications’. These meta-slot modifications are basically property modifiers, and can be used for specifying initial values or for invoking demons for performing actions such as changing inheritance dynamically. Another valuable application of a meta-slot modification is to override the Nexpert Object default query about any object ("what is the value of ...") and make it more specific and meaningful.

The class hierarchy used to represent different classes of fabric defects is shown in Figure 6.2a. The slots of the class FabricDefects are Type, Direction, LengthwisePattern, WidthwisePattern, and Appearance (These attributes are shown in alphabetic in order in Figure 6.2a which is the default order in Nexpert Object output). The Point, Line and Area defect subclasses inherit these slots as shown in the figure. In addition, they also have a slot presence, which is a Boolean to indicate whether a defect belonging to that subclass is present in the fabric. The inheritance continues down to the next level of individual defects. For example, Bad_Knot, an instance of PointDefects, inherits the slots Type, Direction and so on, as shown in the figure.

Slots such as group, importance and value are inherited by Bad_Knot from the PointClassif subclass shown in Figure 6.2b. The slots of objects in this second class hierarchy, FabDefectsClassif, shown in Figure 6.2b, do not contain any information about the defects, per se. However, the values of these slots are used to guide the search. The main requirement for avoiding redundancy in searching is to prune all the defects and defect classes which can be discarded based on the already known data. Classes PointClassif, LineClassif, and AreaClassif (short for Point, Line and Area Classification, respectively), inherit the slots group, importance, and value from FabDefectsClassif. The group slot is used to prune whole sets of defects, which do not have the same
Figure 6.1 Top Level of the Two Class Hierarchies in FDAS
Figure 6.2a  Class Hierarchy for Representing Fabric Defects
Figure 6.2b  Class Hierarchy for Inference Control
identifying group of visual attributes matching those given by the user as characteristic of the defect being observed. The *importance* slot is used to focus the search only on that group of defects which remains under consideration after initial pruning.

The intersection sets representing all possible combinations of Directions and Lengthwise and Widthwise Patterns, named as shown in Figure 5.2, form subclasses under *PointClassif*, *LineClassif*, and *AreaClassif*. Individual defects such as *Bad Knot* and *Missing Pick* are instances of the subclass corresponding to the intersection set to which they belong. For example, in Figure 6.2b, *Bad Knot, Finger Mark, Fuzz Balls*, etc., are instances of the subclass *NPO_WRFI*. An individual defect may belong to more than one intersection set owing to technological reasons, and hence can inherit the slot values from any of the corresponding subclasses. Shown at the top of Figure 6.2b, *Bad Knot* is an instance of three classes, i.e., *PointDefects, NPO_WRFI*, and *NPO_WIFI*.

Another mechanism called ‘context linkage’ available in Nexpert Object is used to establish which of the set of defects are to be considered once a defect sub-class is selected according to the user’s input specification of a defect’s visual characteristics. This leads to great economy of time in the actual diagnosis process, since only a small active set of defects is considered instead of the system’s inference engine ranging over the entire domain of defects to check if they indeed could be present and exhibit this particular visual signature.

### 6.2 Three-tier Rule Base

As described in section 5.2, hierarchical classification of the fabric defects domain, with early pruning, was identified as the most suitable means for efficiently searching the defect that matches the user’s description. This strategy is implemented using three levels of rules for progressively narrowing down the domain to be searched by pruning the defects (and defect classes) which do not match the user’s description, early in the search. FDAS employs the strategy used in many medical diagnosis systems, that of ‘category hypotheses’ to identify homologous groups of defects (or diseases) and ‘defect hypotheses’ to identify individual defects (or diseases). The first two levels of rules identify progressively narrower subgroups of defects, and the third level rules are used to identify the individual defect out of the residual smallest subgroup identified by the first two levels as most relevant.

An example of a set of rules for identifying a Bad Knot is shown in Figures 6.3a. The working of the rules is shown in Figure 6.3b, which is a transcript generated by FDAS during its working and written to a file at the end of the session.

**Level One Rules.** At the beginning of the session, FDAS queries the user about the fabric defect *Type*, i.e., Point, Line or Area. Depending on the user’s response, it will ask further questions about the specific defect’s *Direction, LengthwisePattern* and *WidthwisePattern*. For example, suppose the inspector sees a Bad Knot, he/she describes the defect *Type* as "Point", the *Direction* of the defect as "No Preferred Orientation", *LengthwisePattern* as "Random", and *WidthwisePattern* as "Isolated". The data volunteered by the user are filled into appropriate slots. This part of the inferencing is shown in Section A of Figure 6.3b. The *Type* of the defect - Point, Line,
LEVEL 1 : Rule 54
If |FabricDefects|.Type is "Point"
Then PointClassif is confirmed.
And |LineDefects|.presence is set to FALSE
And |AreaDefects|.presence is set to FALSE
And LineClassif.group is set to FALSE
And AreaClassif.group is set to FALSE

LEVEL 2 : Rule 48
If there is evidence of |PointClassif|
And |PointDefects|.Direction is "No Preferred Orientation"
And |PointDefects|.LengthwisePattern is "Random"
And |PointDefects|.WidthwisePattern is "Isolated"
Then NPO_WRFI is confirmed.
And |PointClassif|.group is set to FALSE
And |NPO_WRFI|.group is set to TRUE
And 100 is assigned to |NPO_WRFI|.importance

LEVEL 3 : Rule 3
If there is evidence of |NPO_WRFI|.group
And there is evidence of Knot_Tails_Too_Long
Then Bad_Knot.presence is confirmed.
And <|PointDefects|>.presence is set to FALSE
And Show "causes/knots_long_tails"
@KEEP=TRUE;@WAIT=FALSE;

Figure 6.3a  Three Levels of Rules for Bad Knots - a Typical Point Defect
SECTION A
Filling Slots With User Volunteered Data

FabricDefects.Type is set to Point
PointDefects.Direction is set to No Preferred Orientation
PointDefects.LengthwisePattern is set to Random
PointDefects.WidthwisePattern is set to Isolated

SECTION B
Level One Rule

Condition if FabricDefects.Type is "Point" in rule 54. (True).
Rule 54 is set to true
PointClassif is set to True
RHS: LineDefects.presence is set to FALSE in rule 54
LineDefects.presence is set to False
RHS: AreaDefects.presence is set to FALSE in rule 54
AreaDefects.presence is set to False
RHS: LineClassif.group is set to FALSE in rule 54
LineClassif.group is set to False
RHS: AreaClassif.group is set to FALSE in rule 54
AreaClassif.group is set to False

SECTION C
Rejection of Discarded Subclasses

Rule 8 is set to false
CL_WCFI is set to False
Rule 9 is set to false
CL_WReFI is set to False

Rule 46 is set to false
NPO_WReFI is set to False
Rule 47 is set to false
NPO_WReFR is set to False

Continued...
SECTION D
Level Two Rule

Condition there is evidence of |PointClassif| in rule 48. (True).
Condition |PointDefects|.Direction is "No Preferred Orientation" in rule 48. (True).
Condition |PointDefects|.LengthwisePattern is "Random" in rule 48. (True).
Condition |PointDefects|.WidthwisePattern is "Isolated" in rule 48. (True).

Rule 48 is set to true
NPO_WRFI is set to True
RHS: |PointClassif|.group is set to FALSE in rule 48
PointClassif.group is set to False
RHS: |NPO_WRFI|.group is set to TRUE in rule 48
NPO_WRFI.group is set to True
RHS: 100 is assigned to |NPO_WRFI|.importance in rule 48
NPO_WRFI.importance is set to 100

SECTION C
Rejection of Discarded Subclasses

Rule 49 is set to false
NPO_WRFR is set to False
Rule 50 is set to false
PL_WIFI is set to False

.................
.................
.................

PW_WRFI is set to False
Rule 58 is set to false
PW_WRFR is set to False
Rule 37 is set to false

Continued...
SECTION E
Level Three Rule

Condition there is evidence of \{NPO-WRFI\}.group in rule 3. (True).
\texttt{Knot\_Tails\_Too\_Long} is set to True
Condition there is evidence of \texttt{Knot\_Tails\_Too\_Long} in rule 3. (True).
Rule 3 is set to true
\texttt{Bad\_Knot.presence} is set to True
RHS: \langle|PointDefects|\rangle.presence is set to FALSE in rule 3
\texttt{Bad\_Knot.presence} is set to False
\texttt{Burnt\_Holes.presence} is set to False

\texttt{Neppy\_Fabric.presence} is set to False
\texttt{Tear\_Drop.presence} is set to False
RHS: Show "causes/knots_long_tails"
@KEEP=TRUE;@WAIT=FALSE; in rule 3
\texttt{Bad\_Knot.presence} is set to True

Figure 6.3b Transcript of a Diagnostic Session for Bad Knots.
or Area, is used to classify the fabric defects at the first level with a rule such as Rule 54 in Figure 6.3a. Once the fabric defect Type is set to "Point", the value of PointClassif is set to true. To confine the search to the broad class of Point Defects and thereby speed up the system response, the Line and Area Defect classes are pruned by FDAS. As shown in Section B (Figure 6.3b), LineDefects.presence, AreaDefects.presence, LineClassif.group and AreaClassif.group are set to false; when this rule is fired, these values are automatically inherited by their subclasses. Section B of Figure 6.3b shows these steps. The role of the "presence" and "group" slots in the lower level rules will be explained in the following two sections; essentially, they eliminate the corresponding fabric defect classes from further consideration.

**Level Two Rules.** At this second level, FDAS further narrows the focus of search by using the other data volunteered by the user. The Level Two rule, Rule 48 in Figure 6.3a, uses the hypothesis of Rule 54 i.e., PointClassif, and the rest of the volunteered data about the Direction and LengthwisePattern and WidthwisePattern to prove NPO_WRFI. That is, this subclass is identified as one whose contents (individual fabric defects) all share that particular mode of occurrence, or set of visual characteristics. Once a particular defect's subclass is identified, further search is efficiently carried out in two steps:

1. FDAS focuses its search on only those defects belonging to the subclass established to be true -- NPO_WRFI in this case.
2. FDAS explicitly establishes that the defect described by the user does not belong to any of the other subclasses so that the inference process need not establish this from the volunteered data.

The group slot of a particular subclass is one of the data required to be true to establish the presence of any defect belonging to the subclass. Hence, the group slot is used to set evidence for whole classes of defects to be true or false. This is accomplished through actions 1 and 2 triggered by the firing of Level Two rules. The importance slot is used to direct the search to the set of rules leading to a particular class of defects. It is accomplished by the third action triggered by the firing of Level Two rules. The actions in this example are explained below (Refer to Rule 48 in Figure 6.3a and Section D in Figure 6.3b).

**Action 1.** NPO_WRFI.group is set to true.
**Action 2.** PointClassif.group is set to false. This value is inherited by all the other subclasses of PointClassif such as CL_WCFI or CL_WRFR, with the exception of NPO_WRFI whose group value has been explicitly set to true by action 1. Note that the Level One Rule 54 had already set LineClassif.group and AreaClassif.group to false, thereby setting the group slots of all their subclasses to false, using inheritance.

**Action 3.** In Nexpert Object, one method of explicitly changing the priority of a rule during an inference process is to use "category numbers." Rules with hypotheses having higher category numbers are considered first, and the category numbers can be reset dynamically. The importance slot of any class is used as the dynamic inference category number of each of the defects which are instances of that particular class. In this case NPO_WRFI.importance is raised to 100 from the default value of 1 (Section D in Figure 6.3b). Hence the search is explicitly focused on the subclass of defects which matches the user description. This part is shown in Section D of Figure 6.3b. The values of other defect subclasses such as CL_WCFI, CL_WRFR, etc., are set to false, in their alphabetical order, as shown in section C of Figure 6.3b.
Level Three Rules. The default inference mechanism of Nexpert Object imposed two major restrictions on the design of the Level Three rules. The working of the inference mechanism could not be altered to overcome these restrictions.

By the default mechanism (backward chaining), if a particular hypothesis is proven to be false by one rule, Nexpert Object directs the search to other rules leading to the same hypothesis. For example, if Bad_Knots is not proven by Rule 3, where it is considered to be an instance of the subclass NPO_WRFI, the system will still try to prove it as an instance of NPO_WIFI, which is already known to be false. Since each defect is an instance of four subclasses on an average, and since some defects can occur as an area defect and a line defect (e.g., thin yarn, blend variation in yarn), such redundant searching will increase the time required for inferencing. To avoid redundant backward searching, rules of Level Two must be linked to rules of Level Three only in the forward direction. This can be achieved if the data required for Level Three Rules are not the principal hypotheses of the Level Two Rules, but are changed by the actions caused by the firing of Level Two Rules. Such one-way linking between rules is called a "weak link" in Nexpert Object. Since FDAS is expected to be used mainly for identifying the defect from a description of visual attributes, i.e., in data driven mode, and since it is necessary to minimize the inference time, it was decided to introduce weak links between Level Two and Level Three rules.

Rule 3, a Level Three Rule for the defect hypothesis Bad_Knots, does not use the principal hypothesis (i.e., NPO_WRFI) of the second stage rule, as its datum. Instead, it uses NPO_WRFI_group as a datum, which was set to true by an action triggered by firing the second-stage Rule 48. Any change in the value of NPO_WRFI_group directs the inference to all the rules with NPO_WRFI.group as one of their data, such as Rule 3. They are not linked in the backward direction because Rule 3 and Rule 48 do not share any data or hypotheses. Such "only forward" or "weak" linking between rules of Levels Two and Three helps avoid redundant search.

FDAS seeks information from the user about the Direction, and Lengthwise and Widthwise Patterns of the defect by presenting a menu with all the possible descriptions of each of these attributes. Since these attributes have only a limited number of descriptions to be considered, they can be displayed in a single menu. However, in the case of Appearance of the defect, FDAS presents the descriptions one by one, until the user confirms one of them. This is because Appearance has a unique description for each defect.

After pruning classes of defects based on the description of the other attributes, one would expect FDAS to question the user only about the Appearance of the defects, which have not yet been rejected. However, the menu presented by Nexpert Object, by its default functioning, contains all possible Appearance descriptions, including those corresponding to the already rejected defects. Since it is impossible for the user to go through a menu of approximately 85 items and make a selection, the user is presented with the Appearance descriptions one by one. It is achieved by having each Appearance description as a boolean variable, in contrast to Direction and Lengthwise and Widthwise patterns, which take strings for their values.

Once the user confirms a particular Appearance description, FDAS establishes the presence of the corresponding defect. The inference process must not attempt to establish the presence of other defects after confirming the presence of one. To prevent such redundant search, the presence
of every other defect has to be explicitly set to false. Consider Section E of Figure 6.3b in which
the user confirms the defect appearance to be "Knot_Tails_Too_Long". This, along with the other
already established datum -- NPO_WRII.group -- confirms the defect described by the user as
Bad_Knots. This is established in FDAS by setting Bad_Knots.presence as true. To prevent FDAS
from trying to establish the presence of other Point Defects, PointDefects.presence is set to false.
This slot is inherited by all the Point Defects with the exception of Bad_Knots, and hence explicitly
set to false, in Rule 3, Figure 6.3a. At the very first level, Rule 54 had already set all Line and Area
Defects to false by setting LineDefects.presence and AreaDefects.presence to false. This scheme
prevents FDAS from considering other defects after confirming any single defect.

The primary consequence (as far as the user is concerned) of confirming the presence of
Bad_Knots, is the display of a text file showing the conclusion of the system about the defect’s
identity, and a list of plausible causes and suggested remedies. This is done using the “Show” com­
mand in Rule 3 of Figure 6.3b. The text window can be kept displayed as long as the user wants.
The working of the Level Three rule is shown in Section E of Figure 6.3b.

Additional Classification: Since Bad_Knots belongs to a subclass of defects with only six
defects in it (see NPO_WRII in Figure 6.2b), it is easy to reach a conclusion regarding the identity
of the defect without further classification. On the other hand, a subclass such as AreaNPO_WIFR
has 19 defects in it as shown earlier in Figure 5.3. These 19 defects have been categorized into four
intermediate sub-categories based on commonalities of their appearance:
1. Stains/Shade Variation
2. Holes/Torn Fabric
3. Knots/Stretched Warp Yarns
4. Others

The implementation of this additional sub-categorization as an additional condition in Level Three
rule is shown in Figure 6.4a (Area Defect), and its working is shown in section E of Figure 6.4b.
Such sub-categories are very useful for speeding up the search for the current defect. Instead of
the user being asked to select from among 16 individual defect Appearance descriptors, it is faster
(in the average case) to select one of the four sub-categories and then be presented with a much
smaller set of Appearance descriptors for matching.

6.3 User Interface

A well-designed computer system should encourage the user to explore all possible ways
of using the system in performing the task better. One of the main barriers to achieving this goal
is the anxiety of the users about making mistakes, and a general apprehension about anything new.
User-friendly interfaces can go a long way in dispelling the anxiety of the user as quickly as possible,
and in providing guidance in every aspect of interaction with the system. A good interface
will not only minimize the possibility of user errors, but also be more tolerant towards the errors
and boost the confidence level of the user. The strengths and weaknesses of the current DOS version
of FDAS’ user interface (UI) are discussed along with ways of overcoming the drawbacks.
LEVEL 1 : Rule 232
If FabDefects.Type is "Area"
Then AreaClassif is confirmed.
And |PointDefects|.presence is set to FALSE
And PointClassif.group is set to FALSE
And |LineDefects|.presence is set to FALSE
And LineClassif.group is set to FALSE

LEVEL 2 : Rule 247
If there is evidence of |AreaClassif|
And |AreaDefects|.Direction is "No Particular Orientation"
And |AreaDefects|.LengthwisePattern is "Isolated"
And |AreaDefects|.WidthwisePattern is "Random"
Then AreaNPO_WIFR is confirmed.
And |AreaClassif|.group is set to FALSE
And |AreaNPO_WIFR|.group is set to TRUE
And 100 is assigned to |AreaNPO_WIFR|.importance

LEVEL 3 : Rule 331
If there is evidence of |AreaNPO_WIFR|.group
And |AreaNPO_WIFR|.SubGroup is "Stains/Shade Variation"
And there is evidence of Ill Defined Areas of Different Shade
Then Shade Variations_in_Fabric_Dyeing.presence is confirmed.
And <|AreaDefects|>.presence is set to FALSE
And Show "causes/color_var" @KEEP=TRUE;@WAIT=FALSE;

Figure 6.4a Three Levels of Rules for Shade Variation in
Fabric Dyeing - a Typical Area Defect
SECTION A

FabDefects.Type is set to Area
AreaDefects.Direction is set to No Particular Orientation
AreaDefects.LengthwisePattern is set to Isolated
AreaDefects.WidthwisePattern is set to Random

SECTION B

Condition FabDefects.Type is "Area" in rule 232. (True).
Rule 232 is set to true
AreaClassif is set to True
RHS: |PointDefects| . presence is set to FALSE in rule 232
PointDefects . presence is set to False
RHS: PointClassif . group is set to FALSE in rule 232
PointClassif . group is set to False
RHS: |LineDefects| . presence is set to FALSE in rule 232
LineDefects . presence is set to False
RHS: LineClassif . group is set to FALSE in rule 232
LineClassif . group is set to False

SECTION C

Rule 225 is set to false
AreaCL WCFC is set to False
Rule 226 is set to false
AreaCL WCFI is set to False
Rule 245 is set to false

AreaNPO WReFR is set to False
Rule 246 is set to false
AreaNPO WRFC is set to False

SECTION D

Condition there is evidence of |AreaClassif| in rule 247. (True).
Condition |AreaDefects| . Direction is "No Particular Orientation"
in rule 247. (True).
Condition |AreaDefects| . LengthwisePattern is "Isolated" in
rule 247. (True).

Continued...
Condition \texttt{|AreaDefects|.WidthwisePattern} is "Random" in rule 247. (True).
Rule 247 is set to true
\texttt{AreaNPO\_WIFR} is set to True
\texttt{RHS: |AreaClassif|.group} is set to \texttt{FALSE} in rule 247
\texttt{AreaClassif.group} is set to False
\texttt{RHS: |AreaNPO\_WIFR|.group} is set to \texttt{TRUE} in rule 247
\texttt{AreaNPO\_WIFR.group} is set to True
\texttt{RHS: 100 is assigned to |AreaNPO\_WIFR|.importance} in rule 247
\texttt{AreaNPO\_WIFR.importance} is set to 100

SECTION C

Rule 248 is set to false
\texttt{AreaNPO\_WRFR} is set to False
Rule 249 is set to false
\texttt{AreaPL\_WIFC} is set to False

SECTION E

Condition there is evidence of \texttt{|AreaNPO\_WIFR|.group} in rule 258. (True).
\texttt{AreaNPO\_WIFR.SubGroup} is set to \texttt{Stains/Shade Variation}
Condition \texttt{|AreaNPO\_WIFR|.SubGroup} is "Stains/Shade Variation" in rule 258. (True).
\texttt{Discoloration\_or\_Foreign\_Matter} is set to False
Condition there is evidence of \texttt{Discoloration\_or\_Foreign\_Matter} in rule 258. (False).
Rule 258 is set to false
\texttt{Beam\_or\_Fabric\_Contamination.presence} is set to False

Condition there is evidence of \texttt{|AreaNPO\_WIFR|.group} in rule 331. (True).

\textit{Continued...}
Condition |AreaNPO_WIFR|\.SubGroup is "Stains/Shade Variation" in rule 331. (True).
Ill_DEFINED_Areas_of_Different_Shade is set to True
Condition there is evidence of Ill_DEFINED_Areas_of_Different_Shade in rule 331. (True).
Rule 331 is set to true
Shade_Variations_in_Fabric_Dyeing\.presence is set to True
RHS: <|AreaDefects|>.presence is set to FALSE in rule 331
Abrasion_from_Fabric_Mishandling\.presence is set to False
Apron_Marks\.presence is set to False
Bowed_Filling\.presence is set to False
..............................................................
..............................................................

Variable_Selvedge_Dyeing\.presence is set to False
Wavy_Fabric\.presence is set to False
Wavy_Selvedge\.presence is set to False
Wrong_Pattern\.presence is set to False
RHS: Show "causes/color_var" @KEEP=TRUE;@WAIT=FALSE; in rule 331
Shade_Variations_in_Fabric_Dyeing\.presence is set to True

Figure 6.4b Transcript of the Session for Shade Variation from Fabric Dyeing
Interaction Style and Medium: The users of the system, i.e., personnel responsible for fabric inspection, are unlikely to be good typists. The same defect can be described differently by different users. Hence, using natural language description or command language for user interaction with the system is difficult. Since menu selection has several advantages, it has been chosen as the main mode of user interaction with the system. It does not require the user to commit anything to memory and needs minimum learning. Using menus greatly minimizes keystrokes. The user is presented with data in a structured way for decision-making. On the other hand, going through many menus one after another is a slow process even with a rapid display rate. One way of overcoming this disadvantage is by displaying all the menus together, and allowing the user to make one selection from each menu. The menu displays of FDAS are very clearly laid out and involve only simple selections.

Semantic Organization of Menus: The UI menus in the system have been hierarchically decomposed, following the meaningful categorization of the underlying defects classification scheme. For example, the menus for selecting the extent and direction of defects are displayed in the following order: Partially Along the Length, Continuously Along the Length, Partially Across the Width, Continuously Across Width and No Preferred Orientation.

Reversal of Actions: The menus for seeking data have been organized in such a way that there is no overlap in the information sought in any two menus. This should reduce the need for the user to change the response to any of the earlier queries at a later stage. But, knowing that the actions taken at any stage are reversible will certainly alleviate the user's anxiety about committing errors. The current DOS version of FDAS allows the user to change any of the already volunteered data at any point during a diagnosis session. But if the user changes his/her mind at a late point in a session, he/she may be required to go through three levels of menus or restart the session from the beginning. In future versions of the system, all the menus should be displayed in a table throughout the session with the user-volunteered data highlighted. It should be possible for the user to change the volunteered data just by clicking on some other choice in the menu with the mouse. Not having to remember the responses to earlier queries will also reduce the cognitive load on the user.

Reduction of Short-Term Memory Load: The number of choices to be considered in a menu ranges from three for Fabric Defect Type to five for the Defect Direction. This is well within the limitation of human-information processing in short-term memory, as many studies [Mill81, Kige84] have established that menus with up to eight items maximize user speed and minimize error rate. The "depth of interaction" i.e., the number of menus that a user has to go through is as important as the "width of each interaction" or the number of items in each menu. With FDAS, the user has to go through five levels of menus if the subclass has eight or fewer defects, and six levels if there are more defects in the subclass (because of the additional intermediate sub-categorization; please see Section 6.2).

Output Organization: All the output from FDAS is in the form of text in separate pop-up windows. The user interface shown in Figure 6.1 is distinct from the full-blown graphical interface for developers using Nexpert Object. The default output is the final diagnosis, comprising the name of the defect just identified, its probable causes and suggested remedies. The location as well as display duration of this pop-up window display are completely under the control of the user. Other output screens or menus are displayed if the user makes an error, or if there is an intermediate sub-
categorization in the sub-class described by the visual defect characteristics.

**Response Time:** Since the system is to be used by the fabric inspector on the shopfloor, it is extremely important that the system responses be as fast as possible. If the system takes too long to respond, it will not only cause loss of production, but will also lead to impatience on the part of the user, and ultimately to disuse of the system itself. FDAS' response is almost instantaneous for displaying the series of menus which enable user input of the defect's visual characteristics. Most diagnosis sessions take 5-7 seconds after user input has been completed to display the analysis and recommendations. Even where a further level of menus is necessary, actual system working time is still about 10 seconds, and only about 30% of overall session elapsed time. This is because most of the session elapsed time is a function of the time the user takes to indicate menu selections, read defect descriptions, etc. Most diagnosis sessions take between 10-20 seconds.

**Error Handling:** The chances for user error have been minimized by using menu selection as the predominant style of user interaction. Only in two cases, FDAS may not be able to reach a conclusion based on the information supplied by the user. In one instance, the user supplies a description of a defect as a set of characteristics which are physically impossible or self-contradictory. In the other, the user may not have accepted any of the defect appearance descriptors as matching what is actually seen on the fabric. In both the cases, FDAS displays an error message prompting the user to redescribe the defect.
CHAPTER 7

SEWING DEFECTS: KNOWLEDGE ACQUISITION

The first step in the development of a sewing defects analysis system is to acquire and organize information on sewing defects, their causes and remedies. This chapter presents a detailed account of the tasks carried out to accomplish this objective.

Another aim during this phase of the research has been to define the specifications of the software system more accurately. Factors considered in this process were possible applications, user profiles, further extensibility and response time requirements.

7.1 Garment Defects: Sources of Knowledge

The bulk of the literature reviewed concerning sewing and assembly defects were books and Federal/military specifications. Useful information was also derived from a series of interviews with technical experts at academic institutions and apparel plants. The garment inspection process, and the procedures used for sampling and re-work of defectives were carefully studied at a number of apparel plants.

Military and Federal specifications provided details of the construction of utility trousers and the quality inspection procedures used in manufacturing. One of the specifications dealt exclusively with garment defects and their varied levels of seriousness. Some of the specifications provided effective guidelines for identifying defect-prone tasks and processes, and for studying garment assembly, machines and inspection procedures during plant visits.

MIL-STD-87062A is the military specification which lays out material requirements and assembly sequences to be used by an apparel contractor to manufacture denim utility trousers to meet service requirements. It also refers to other official documents for the design, manufacture and quality inspection of all constituents such as fabric, buttons, zippers, sewing thread, and packing material. All the processes in the manufacture of a utility trouser, from the cutting to final garment inspection and packaging are described in detail.

MIL-STD-1488F is another specification used by the military to provide guidelines for inspectors checking the quality of various types of trousers (including utility denim). Garment defects are classified into critical, major and minor types; they are also sub-divided into categories based on their type and location on the trouser. Details of sampling schemes per production lot are supplied. Every defect description is accompanied by a penalty point assignment; the cumulative point accumulations define acceptance and rejection thresholds for each production lot at different levels of inspection.

Other Standards and specifications provide details on the various types of seams and stitches used (Federal Standard #751), and on the required structure and performance of the fabric used to produce the garment (e.g., MIL-C-24915 for fire-retardant cotton denim). The Federal Specifi-
cations V-B-871, V-F-106, and V-T-280 are publications dealing with the construction and performance of buttons, slide fasteners and cotton buttonhole thread, respectively. A large amount of detail is also available on recommended procedures for statistical sampling for quality evaluation and identification measures for storage and shipment. All these documents provide very important guidelines for characterizing the garment defects domain. Several aspects of the specifications, e.g., the construction sequences laid down in MIL-STD-87062A, have influenced the structure of the software.

Several textbooks served as sources of information on current apparel manufacturing practices, machinery and processes, cutting and sewing sequences for different types of garments and inspection norms. These books also provided an overall picture of the impact of classification and analysis of defects in the sewing room on the percentage of first quality production, operator assessment, machine monitoring and production planning. Typical of these are the "Apparel Manufacturing Handbook" by Solinger [Soli 80], "Guide to Apparel Manufacturing" by Peyton Hudson [Huds 88], the "Quality Control Handbook" by J. M. Juran [Jura 74], and "An Introduction to Quality Control for the Apparel Industry" by Pradip Mehta [Meht 85].

Several research papers gave deeper insight into some facets of the domain of apparel manufacturing including defects. Some of these pertained to the quality of fabric and trim elements, and others treated quality maintenance within the various operations such as cutting and sewing. Other papers and technical reports presented research into specific types of defects such as seam pucker, and the various organizational aspects and importance of quality control methods and procedures.

Perhaps the most important source of information was the technical consultations and discussions relating to the economic and technical aspects of apparel defects with experts at AMTC. These discussions initially attempted to enumerate different types of defects arising in a trouser manufacturing operation, and to describe them in the most efficient yet comprehensive way. The focus then shifted to assessing the potential of each assembly process to generate each of the enumerated types of apparel defects. This process resulted in a complete map of causal relationships between every kind of manufacturing parameter at every stage of assembly and possible defects which could be generated in the product. The experts also assisted in identifying the remedies for different defects.

Using procedures similar to that for FDAS, the domain was analyzed, followed by the development of a defects classification scheme. For SDAS, the classification centered around two primary decision criteria: the location of the defect, and the nature of the defect. These classification criteria were found to be adequate for describing each defect uniquely and for advising on that defect’s causal factors and prescription of remedies. It was decided to incorporate the utility trouser construction specifications (MIL-STD-87062A) in the SDAS software; using this, SDAS would be able to render relevant advice regarding construction standards for the operation that is judged to be responsible for a particular defect.
7.2 Classification Scheme

The defects classification scheme is structured around two main criteria: the location of the defect, and the nature of the defect. These are the two major visual cues that an inspector derives from the garment being inspected. This two-component input from the inspector immediately points the system software in the right direction. The software would then have to precisely determine the manufacturing stage or assembly process that caused this defect, questioning the user further if necessary. Once the manufacturing operation is identified, the software can suggest probable causes and remedies.

The "Nature of Fault" descriptor is further split into several subclasses as shown in Figure 7.1. These subclasses are further classified wherever necessary. Other subclasses can also be classified as needed. For instance, the subclass Appearance has not been classified further since most items in this subclass stem from fabric defects, which is a domain covered by FDAS.

Most defects in the Position/Alignment/Incorrect Component category have been subsumed into the Seam Formation, Stitch Formation or Others categories. Also, in Figure 7.1, Raw Edge defect, because it is not clearly assignable to either of the Seam Formation or Stitch Formation categories, is listed under both the categories.

Figure 7.2 illustrates the "Defect Location" classification hierarchy. Since the military utility trouser has a very simple construction with fewer parts compared to most other garments, the class hierarchy is also simple.

There is another set of classes which comprises the "Specification" set. This is a hierarchy of classes containing the entire MIL-STD-87062A specification dealing with operational parameters and processes. These organize the garment construction data available in the specification document, so that the relevant specifications can be referred to for recommendations pertaining to the operation deemed responsible for the defect being examined by the user.

7.3 Defect Occurrences and Causal Factors

As in the case of FDAS, the model chosen here is of the associational type. The reason for preferring this over a detailed causal model are the difficulties associated with fully understanding and representing all the relationships between entities in an exhaustive way. In the domain of garment manufacturing defects, diagnostic information is predominantly heuristic. However, there are some cause-effect relations which may be rigidly codified and generally applicable. (An example of this would be "cutter lean", which is a stacking defect at the cutting table which would cause all the parts within a certain bundle to have some of their dimensions progressively going out of tolerance).

A hybrid formal representation is chosen for representing the entities in this domain of sewing defects, comprising class-object hierarchies and rules. Since the entities in the domain knowledge were hierarchically classifiable, it was possible to represent them using classes and objects. The use of class hierarchies has several advantages such as making the knowledge in SDAS highly
Figure 7.1 "Nature of Defect" Classification Hierarchy
structured, and in explicitly rendering the relationship between different entities within the knowledge base. However, the part of the rule base using entity descriptions for actual diagnosis inferencing, and those rules controlling this inferencing process are not as clearly distinguishable as in the structure of FDAS (the latter accomplishes its modularity by the use of two distinct class hierarchies).

As with FDAS, classes and objects represent categories of defects and individual defects and rules are used to identify defects based on user description.

There are currently 18 major types of sewing and assembly defects treated in SDAS, within the sub-categories Stitch Formation, Seam Formation and Other Defects. However, analogous to the different modes in which each one of the fabric defects can occur in FDAS, each of the assembly defects can arise at any stage in the manufacturing sequence. Depending on the origin, the cause may be any one of a variety of factors. Hence, the SDAS software relies on a scheme which combines two types of diagnosis information, general and specific. General diagnosis and correction measures are those which would hold and be correct irrespective of the operation which gave rise to a particular defect on the garment. On the other hand, most defects can have specific causal factors at individual operations within the garment assembly sequence, whether they are caused by operator, machine, or process parameters. SDAS has access to such specific diagnostic information.

Once the manufacturing operation responsible for the defect is determined, the general diagnosis for that defect and the relevant specific diagnosis are dynamically combined by SDAS in a context-sensitive manner and displayed to the user. As in the case of FDAS, the diagnosis information is stored in text files. They are thus very easy to modify and customize using any simple text editor. Even if an organization wishes to refine the diagnosis down to machine specifics, e.g., stitch gauge settings on a Brother® sewing machine, this can be accomplished easily.

7.4 Special Defects in Denim Trouser Assembly

There are some special considerations in any assembly process that uses cotton denim cloth of the usual weights. A typical characteristic of such cloth is its high stiffness and tightness of weave. While this renders a common problem such as seam pucker more easy to avoid, such dense and stiff fabric usually causes excessive thermal and abrasion stresses on a machine’s moving parts, leading to greater wear and tear. Since the size of sewing thread is also bigger, there are likely to be large frictional effects in the needle zone.

Another problem in assembling utility trousers from cotton denim is the generation of relatively high proportions of lint and fly in the sewing room. One reason for this is the use of soft-twisted cotton yarn in the filling direction; another is the rubbing off of indigo-dye particles from the cloth due to friction with the fast-moving stitching components on the sewing machine. On the other hand, because of the all-cotton content of the garment components, there is little static attraction and clinging tendency. Therefore, each piece in a bundle is likely to maintain its shape and place and not be susceptible to folding on itself due to surface effects.

There are two major aspects of the construction of denim utility trousers that set them apart
Figure 7.2 "Location of Defects" Classification Hierarchy
from the assembly of other garments. One is the very simple construction of this garment, which has fewer operations than most other trouser assembly sequences. Pocket design and attachment are very simple, and each belt loop has positioning clues on the garment which minimizes errors. This also contributes to reduced errors in pattern design, cutting, bundle mix-ups and faulty component positioning.

The second is the preponderance of double-felled double-lapped seams. This results in a larger percentage of certain sewing errors (such as needle chew when one seam runs across another and fabric thicknesses jump by over 100%) and less of others (such as a raw edge). This type of seam requires the machine folders to be in good condition. The construction of the waistband may also give rise to a rather uncommon set of errors in alignment of the main panels with the long edge of the waistband and alignment of the turned-in waistband corners.
CHAPTER 8

SEWING DEFECTS: REPRESENTATION AND REASONING

In this chapter, the conceptual design for the domain of garment defects, and the formal mapping of this conceptual model into software are discussed. A scheme for the visual identification of sewing defects is presented, along with a suitable defects classification scheme. Following this, the chosen modes of analysis and diagnosis using this representation scheme are discussed.

8.1 Partitioning the Set of Defects

As described in 7.2, the classification scheme is structured around two main criteria: the location of the defect and the nature of the defect. The hierarchy trees are expressed as class-object structures similar to those implemented in FDAS, for purposes of modularity, ease of testing and later modification. All major defect type classification entities (Nature of Defect) and their type groupings (e.g., Seam Formation) are classes, as seen in Figure 8.1a. Their contents are sub-classes representing individual types of defects, each of which is in itself a class comprising objects denoting the occurrence of that particular type of defect at each of the manufacturing operations in the assembly sequence. For example, the defect type sub-class Twisted Seam is one of the members of the class Seam Formation, and has as its children the objects Twisted Seam at the Attach Belt Loops Operation, Twisted Seam at the Attach Waistband Operation, Twisted Seam at the Inseam Operation, etc. In a similar fashion, the defect type sub-class Open Seam is developed into a whole list of member objects representing the defect at various manufacturing operations, as is the defect type sub-class Raw Edge and so on. This set of class-object structures also affords a measure of commonality for expressing defect analysis schemes for other garments in the future.

As seen in Figure 8.1b, there are also some class property slots. The most important are the slots op_code and specific_operation. Consider the class Twisted Seam shown and all its children objects; these slots are initialized with different data individually identifying each object. Hence, object Twisted Seam at the Attach Belt Loops Operation will contain the data "abl" in its slot op_code and the data "Attach_Belt_Loops" in its slot specific_operation. The object Twisted Seam at the Attach Waistband Operation will contain data "awb" in slot op_code and the data "Attach_Waistband" in the slot specific_operation. As will be seen in Section 9.1, these slots play an important part in the working of the diagnosis rules.

Similarly, the location where these defects appear on the garment is expressed in another class-object structure, as shown in Figure 8.2. It must be noted that this is where the current defects classification scheme departs from generality. This location classification is used for the most efficient and succinct description of the visually-distinct locations and sub-assemblies for denim utility trousers following the MIL-STD-87062A specification. This location classification tree will be different for the structures and assembly sequences of other garments, and the software will therefore have to be customized to deal with those.
Figure 8.1a "Nature of Defect" Class Hierarchy, First Layer

Figure 8.1b "Nature of Defect" Class Hierarchy, Second Layer, Sub-Class "Twisted Seam"
Figure 8.2 "Location of Defects" Class-Object Hierarchy

Figure 8.3 "Current_Defect" Representation Object
The current_defect object is used to collect data about the defect in each diagnosis session, starting out with the user-volunteered identification of defect type and location. As SDAS builds up a profile of the defect during the diagnostic session, more defect characteristics and defect-related information (derived from the inference process) are stored in the slots of this object current_defect (Figure 8.3). Filled squares in the property slot references mean that there are some initial modifications to these properties. These modifications may be used for specifying initial values, invoking demons for performing actions such as changing inheritance dynamically, or to override the Nexpert Object default query about any object ("what is the value of...") and supply in its place one which is more specific and meaningful.

Among the several slots used during the diagnosis session are Boolean slots to represent the status of the overall diagnosis process. The Location slot is used as a datum for the second level of rules, to ensure that the diagnosis has indeed proceeded to the point where the manufacturing operation has been deduced from the information supplied by the user regarding defect location on the garment. The Diagnosis Done Boolean slot is reset from false to true by other rules, once the defect has been analyzed and the diagnosis and recommendations have been displayed, SDAS can then transmit that session’s defect data into a database, if necessary.

As soon as the user selects the location of the defect from the input menu, the response is assigned to the slot Location. The slot Type will contain the corresponding user response for the nature of the defect. The slot Mfg_Operation will be assigned the manufacturing operation responsible for the defect currently being observed. As soon as this likely source is identified, a group of relevant construction norms out of the MIL-STD-87062A document is identified; the name of this specification group is put into the slot Construction_Spec_Group.

As the diagnosis session proceeds, the user supplies a choice for the nature of the defect being seen in the garment; the analysis rules store an abbreviation representing this defect in the slot type_code. For example, if the user sees a bartack misplaced by a half-inch on the crotch junction and therefore chooses Mislocated Reinforcement as the type of defect, the contents of type_code will be the notation "mr". This notation will be modified and added to if there is diagnosis information specific to the Crotch Bartacking operation, which caused this defect.

8.2 Structuring the Diagnosis Knowledge

To permit easy reading and modification of the stored diagnosis files, the system uses a simple scheme of keeping generic and more specific information together in logically-related groups of scripts. Each group is isolated in one filesystem directory. As in the case of FDAS, text files contain all the diagnosis information, and are very easy to modify and customize using any text editor. Even if an organization wishes to refine the diagnosis down to machine specificities, e.g., folder settings on a Pfaff® double-stitch machine, or maintenance schedules for a group of machines, this can be achieved without much difficulty.

At present, SDAS contains diagnosis information for 18 types of sewing and assembly defects within the sub-categories Stitch Formation, Seam Formation and Other defects. Each of these assembly defects can arise at any stage in the manufacturing sequence. For each particular defect, there may be some common causal factors which may be independent of the manufacturing oper-
oration or stage in the assembly sequence. This type of "general diagnosis" information, which would be correct irrespective of the operation which gave rise to that particular defect or its location on the garment, is in a script named with the abbreviation representing the defect. Each of these generalized defect diagnosis scripts resides in a directory bearing the same name. For example, the defect type Open Seam has a generalized diagnosis script "os", residing in a directory "os". The defect type Raw Edge has a generalized diagnosis script "re", in a sister directory to "os" called "re".

Most defects can have specific causal factors at individual operations within the garment assembly sequence, whether they are caused by operator, machine, or process parameters. SDAS has access to such specific diagnostic information. These scripts are labelled in a systematic manner with each label comprising the abbreviation of the defect type first, and a subsequent two- or three-letter abbreviation representing an operation or stage within the manufacturing sequence. Within each directory named by the abbreviated form of the defect type, these specific scripts are also stored for as many operations as have such distinct diagnostic information pertaining to this particular defect type. For example, directory "os" will contain not only diagnostics for Open Seams in general (file "os"), but also specific recommendations for Open Seams at the Attach Belt Loops Operation (file "osabl"), at the Attach Label Operation (file "osal"), at the Attach Left Fly Operation (file "osalf"), at the Attach Patch Pockets Operation (file "osapp"), etc. The operationspecific scripts are in alphabetical order.

Once the assembly operation causing the defect is determined, the general diagnosis for that defect and the relevant specific diagnosis (if one is available) are dynamically combined by SDAS and displayed to the user. For operations which do not have specific diagnosis scripts for a particular defect, only the generalized script is displayed\(^1\).

### 8.3 Representation of MIL-STD-87062A Utility Trouser Construction Specifications

While the construction specifications cannot provide any guidelines for the analysis and diagnosis of defects, they do provide the norms that govern the manufacturing procedures and tolerances at each step in the assembly process. Since the specifications are not likely to change during the operational life of SDAS, it is preferable to incorporate the entire specifications into the Nexpert Object software framework.

As with any Nexpert Object static representation in FDAS or SDAS, the construction specification is expressed as classes and objects. The overall specification groupings of assembly operations are expressed as classes and objects. The topmost level of this hierarchy of classes, shown in Figure 8.4, depicts the various specification groupings corresponding to the assembly operations in the manufacturing sequence(s) laid down by the military procurement authorities for denim utility trousers.

\(^1\) This system of abbreviations for the file names and their manipulation (described later) has been adopted to ensure the working of the SDAS on MS-DOS machines. MS-DOS naming restrictions do not permit file names such as "Open_Seams" or "Open_Seams_at_Operation_Patch_Pocket", which would have been more intuitive.
Figure 8.4 Construction Specification Class-Object Hierarchy, First Level
At the top of Figure 8.5, the class properties are shown. These correspond to the headings seen in the paper document, and are all of the type string. For example, the slot \textit{norm\_description} contains the description of some type of operational advice or requirement, and the slot \textit{stitch\_type} contains a reference to the formation of the seam recommended (with a set of abbreviated descriptors referenced from Federal Standard #751 for seams and stitches) for this operation. The slots contain references to each of the fields in an element within the specification groups, and the overall class structure reflects the operational sequence normally recommended for the manufacture of utility trousers.

Within each heading in the paper document, i.e., within each class in the "Construction Specification MIL 87062," there are a number of objects representing the logically-connected set of specifications within that heading. Since the heading normally comprises several individual specification items in the set, each class will consist of one or more objects. Figure 8 shows the expansion of one of the specification classes, namely, \textit{Join Crotch Seam}. There are two separate specification items in this class, each represented as an object with its slots fully representing all the paper document's norms and recommendations.

During a diagnosis session, the class hierarchy relevant to the defect being observed is available for instantaneous look-up. When SDAS has received the set of visual features regarding the defect, and has arrived at the manufacturing operation most likely to have caused the defect, the group of specifications pertaining to this operation is marked as useful. There is also a way to remove some of these specifications from this selected group, depending on the operational relevance in a particular manufacturing set-up. For instance, an organization may follow a small variation of the manufacturing sequence, or it may have a completely modernized set of machinery in the sewing room. In that case, some of the norms and requirements are of little value. These can be disabled by setting the slot \textit{Operationally Relevant Spec} to a Boolean value of False. Such settings are to be made when customizing SDAS prior to its use in the plant.
Figure 8.5  Construction Specification Class-Object Hierarchy, Second Level
CHAPTER 9
SEWING DEFECTS: SOFTWARE IMPLEMENTATION OF THE ANALYSIS FRAMEWORK

This chapter covers the details of the software development of SDAS, and discusses the arrangement of the reasoning processes to carry out the classification/diagnosis task. In SDAS, domain knowledge is represented using a hierarchy of classes and objects, and reasoning is implemented using rules.

The software implementation is explained and illustrated with two test cases. The first is a simple case of a skipped stitch somewhere along the length of the waistband which will illustrate the fundamental layout of the reasoning mechanism using rules working over the static class-object hierarchy. A detailed transcript of the inference process is provided, showing how a diagnosis is made. The user has also chosen to scan the corresponding sections of the specification document. The second is a more complicated case of an open seam on a belt loop. This example describes the dynamic combination of a generalized set of recommendations with a particular set of specific recommendations for the culprit operation identified by the system. In the second case, the user has not requested to view the relevant construction specifications.

9.1 Working Principles: Analysis and Diagnosis

Nexpert Object has been used for the implementation of SDAS. Separate class hierarchies are used for expressing the criteria Nature of Defect and Location of Defect. Atoms such as Location_Found and slots such as Diagnosis_Done of the atom Curr_Defect are used to flag the status of the defect diagnosis session, and trigger the use of different sets of reasoning rules. The majority of reasoning rules are arranged into two tiers or sets, similar to the arrangement in FDAS. Each set of rules forms a group of associative pattern matchers; one set is keyed upon the "Location of Defect" criterion, and the second on the "Nature of Defect" criterion. The second level of rules consists of matched pairs of rules, one pair for each major type of defect (see Figure 9.1a).

The hypothesis for each pair is the same, but their priorities of action are different. The Level 2(b) rule in Figure 9.1a shows a rule for the defect "Skipped Stitch" which uses a default priority of 1. This rule would only display a generalized diagnosis file for this defect, if it were to operate. The Level 2(a) rule is a more specific rule, with a higher priority of -100. It is an attempt to determine a more detailed profile of the current skipped stitch defect, so that a more specific diagnosis can be made to supplement the generalized one.

The slot Curr_Defect.Location is first volunteered. The slot Curr_Defect.Type is volunteered second. Let us assume that the user sees a Skipped Stitch on the Waistband of the garment, as in Section A of Figure 9.1b.

Level One Rules: The Level One rules now attempt a pattern match on the data given for the Location of the defect. A series of defect location hypotheses is dismissed, as seen in Section B of Figure 9.1b. Then in Section C, a match is found for the second datum in the Level One rule
LEVEL 1: Rule ObservedDef_Waistband
If there is no evidence of Location_Found
And Curr_Defect.Location is "Waistband"
And there is evidence of a Waistband_RightEnd
Then Attach_Waistband is confirmed.
And |Curr_Defect|.Mfg_Operation is set to "Attach_Waistband"
And <|SpecClass_Attach_Waistband|>.Admissible_Spec is set to TRUE
And Spec_Attach_Waistband_And_Size_Label_5.Admissible_Spec
is set to FALSE
And Location_Found is set to TRUE

LEVEL 2 (a): Rule Skipped_Stitch_Def_In_Specific_Operation;
PRI= -100;
If Curr_Defect.Type is "Skipped_Stitch"
And there is no evidence of Curr_Defect.Diagnosis_Done
And <|Skipped_Stitchf|.specific_operation matches
Curr_Defect.Mfg_Operation
Then Skipped_Stitch is confirmed.
And |Curr_Defect|.type_code is set to "ss"
And |Curr_Defect|.OpVector is set to
STRCAT(Curr_Defect.type_code, <|Skipped_Stitchf|.op_code)
And "concat" is Executed
And "tempfile" is Shown (@KEEP=TRUE,@WAIT=FALSE)
And Curr_Defect.Diagnosis_Done is set to TRUE

LEVEL 2 (b): Rule Skipped_Stitch_Defect
If Curr_Defect.Type is "Skipped_Stitch"
there is no evidence of Curr_Defect.Diagnosis_Done
Then Skipped_Stitch is confirmed.
And "causes/ss/ss" is Shown (@KEEP=TRUE,@WAIT=FALSE)
And Curr_Defect.Diagnosis_Done is set to TRUE

Figure 9.1a Two Levels of Rules: Skipped Stitch Defect, on the Waistband
SECTION A
Filling Slots with User Volunteered Data

\texttt{Curr\_Defect.Location} is set to \textit{Waistband}
\texttt{Curr\_Defect.Type} is set to \textit{Skipped\_Stitch}

SECTION B
Rejection of Defect Locations

Rule 36 is set to false
Rule 35 is set to false
\texttt{Make\_Right\_Fly} is set to \textit{False}
Rule 34 is set to false
Rule 33 is set to false
\texttt{Make\_Patch\_Pockets} is set to \textit{False}
\texttt{Join\_Crotch\_ Seam} is set to \textit{False}
Rule 24 is set to false
Rule 13 is set to false
Rule 10 is set to false
\texttt{Bartack} is set to \textit{False}

SECTION C
Level One Rule

Condition there is no evidence of \texttt{Location\_Found} in rule 
\texttt{ObservedDef\_Waistband\_Right\_End} (True).
Condition \texttt{Curr\_Defect\_Location} is "Waistband" in rule 
\texttt{ObservedDef\_Waistband\_Right\_End} (True).
\texttt{Waistband\_RightEnd} is set to \textit{False}
Condition there is evidence of \texttt{Waistband\_RightEnd} in rule 
\texttt{ObservedDef\_Waistband\_Right\_End} (False).
Rule 9 is set to false
\texttt{Attach\_Waistband\_Right\_End} is set to \textit{False}
Condition there is no evidence of \texttt{Location\_Found} in rule 
\texttt{ObservedDef\_Waistband\_Left\_End} (True).
Condition \texttt{Curr\_Defect\_Location} is "Waistband" in rule 
\texttt{ObservedDef\_Waistband\_Left\_End} (True).
\texttt{Waistband\_LeftEnd} is set to \textit{False}
Condition there is evidence of \texttt{Waistband\_LeftEnd} in rule 
\texttt{ObservedDef\_Waistband\_Left\_End} (False).
Rule 8 is set to false
\texttt{Attach\_Waistband\_Left\_End} is set to \textit{False}

Continued...
Condition there is no evidence of Location_Found in rule ObservedDef_Waistband (True).
Condition Curr_Defect.Location is "Waistband" in rule ObservedDef_Waistband_Right_End (True).
Waistband_Length is set to True
Condition there is evidence of Waistband_Length in rule ObservedDef_Waistband (True).
Rule 7 is set to true
Attach_Waistband is set to True
RHS: Curr_Defect.Mfg_Operation is set to "Attach_Waistband"
in rule ObservedDef_Waistband
Curr_Defect.Mfg_Operation is set to Attach_Waistband
RHS: <[SpecClass_Attach_Waistband]> .Admissible_Spec is set to TRUE
in rule ObservedDef_Waistband
Spec_Attach_Waistband_And_Size_Label_1.Admissible_Spec is set to TRUE
Spec_Attach_Waistband_And_Size_Label_23.Admissible_Spec is set to TRUE
Spec_Attach_Waistband_And_Size_Label_2a.Admissible_Spec is set to TRUE
Spec_Attach_Waistband_And_Size_Label_2b.Admissible_Spec is set to TRUE
Spec_Attach_Waistband_And_Size_Label_5.Admissible_Spec is set to TRUE
Spec_Attach_Waistband_And_Size_Label_5.Admissible_Spec is set to FALSE in rule ObservedDef_Waistband
RHS: Location_Found is set to TRUE in rule ObservedDef_Waistband
Location_Found is set to True

SECTION B
Rejection of Defect Locations

Rule 5 is set to false
Rule 6 is set to false
Attach_Right_Fly_To_Right_Front is set to False
Rule 4 is set to false
Attach_Patch_Pockets is set to False

SECTION D
Rejection of Incorrect Defect Types

Rule 62 is set to false
Rule 61 is set to false

Continued...
Wrong Or Irregular Stitch Gauge is set to False
Rule 60 is set to false
Rule 59 is set to false
Uneven Stitch Line is set to False
Rule 58 is set to false
Rule 57 is set to false
Twisted Seam is set to False

SECTION E
Level Two Rules

Condition Curr_Defect.Type is "Skipped Stitch" in rule Skipped-Stitch_In_Specific_Location (True).
Condition there is no evidence of Curr_Defect.Diagnosis_Done in rule Skipped_Stitch_In_Specific_Location (True).
<|Skipped_Stitch|>.specific_operation=Skipped_Stitch_Attach_Belt_Loops,Skipped_Stitch_Attach_Label,Skipped_Stitch_Attach_Pockets,Skipped_Stitch_Attach_Waistband_Left_End,Skipped_Stitch_Inseam,Skipped_Stitch_Make_Belt_Loops,Skipped_Stitch_Make_Left_Fly,Skipped_Stitch_Make_Right_Fly,Skipped_Stitch_Outseam
Condition <|Skipped_Stitch|>.specific_operation is equal to Curr_Defect.Mfg_Operation in rule Skipped_Stitch_Def_In_Specific_Operation (False).
Rule 56 is set to false
Condition Curr_Defect.Type is "Skipped Stitch" in rule Skipped-Stitch_Defect (True).
Condition there is no evidence of Curr_Defect.Diagnosis_Done in rule Skipped_Stitch_Defect (True).
Rule 55 is set to true
Skipped_Stitch is set to True
RHS: Show "causes/ss/ss" @KEEP=TRUE;@WAIT=FALSE; in rule Skipped-_Stitch_Defect
RHS: Curr_Defect.Diagnosis_Done is set to TRUE in rule Skipped-_Stitch_Defect
Curr_Defect.Diagnosis_Done is set to True

SECTION D
Rejection of Incorrect Defect Types

Rule 52 is set to false
Rule 51 is set to false
Run_Off is set to False
...
Rule 12 is set to false
Rule 11 is set to false
**Broken_Thread** is set to False

SECTION F
Display Relevant Construction Specifications

Condition there is evidence of **Curr_Defect.Diagnosis_Done** in rule 54 (True).
**View_Spec** is set to True
Condition there is evidence of **View_Spec** in rule 54 (True).
Rule 54 is set to true
**Select_SpecClass** is set to True
RHS: STRCAT("SpecClass_",**Curr_Defect.Mfg_Operation") is assigned to **Curr_Defect.Construction_Spec_Group** in rule 54
**Curr_Defect.Construction_Spec_Group** is set to SpecClass_Attach_Waistband
RHS:<\Current_Defect.Construction_Spec_Group\.Operationally_Relevant_Spec is set to True
**Spec_Attach_Waistband_1.Operationally_Relevant_Spec** is set to True
**Spec_Attach_Waistband_23.Operationally_Relevant_Spec** is set to True
**Spec_Attach_Waistband_2a.Operationally_Relevant_Spec** is set to True
**Spec_Attach_Waistband_2b.Operationally_Relevant_Spec** is set to True
**Spec_Attach_Waistband_5.Operationally_Relevant_Spec** is set to True
Condition there is evidence of <\Current_Defect.Construction_Spec_Group\.Admissible_Spec in rule 53 (True).
Condition there is evidence of <\Current_Defect.Construction_Spec_Group\.Operationally_Relevant_Spec in rule 53 (True).
Rule 53 is set to true
**Select_Spec_87062** is set to True
RHS: Execute "spec_read" (@STRING="@V(Curr_Defect.Construction_Spec_Group)"); in rule 53
RHS: Show "specfile" @KEEP=TRUE;@WAIT=TRUE; in rule 53

Figure 9.1b  Transcript of a Diagnostic Session for a Skipped Stitch Defect on the Waistband
dedicated to the right end of the waistband. However, that is not where the problem is located, so the matcher continues to a rule which searches for a Location on the left-hand side of the waistband. There is no success there, either.

SDAS then comes to a pattern matching success at the rule which inquires about a defect somewhere along the length of the waistband. This rule then sets the hypothesis "Attach_Waistband" to be true, and proceeds to execute the RHS clauses of the rule. The manufacturing operation most likely to give rise to this defect is set to be "Attach_Waistband"; the entire class of specifications from MIL-STD-87062A dealing with this operation of attaching the waistband to the trouser is deemed as admissible norms. Out of this group of specifications, one is then reset by this rule as uninteresting. (In this case, this specification is discarded because it deals with a process not relevant for a defect along the length of the waist band).

SDAS continues further to reset the remaining Location possibilities (Section B). It must be noted that global hypothesis-class rejection schemes such as those used in FDAS are unnecessary at this point in the development of SDAS, because of the very limited number of defect locations that SDAS has to deal with.

**Level Two Rules:** At the second level, the system’s focus shifts to identifying the nature of the defect, analyzing it and suggesting remedies. Section D in Figure 9.1b shows SDAS removing other defect types from consideration. In Section E, the two rules which share the same "Skipped_Stitch" hypothesis are activated. Since the more specific rule has a higher priority, the transcript shows the Level 2(a) rule being considered first.

The rule comes to its third clause on the LHS, and expands the Skipped Stitch Class into its children objects. These directly correspond to specific diagnosis scripts available for different operations. If there is no specific diagnosis script for a particular manufacturing operation, there will be no corresponding child object in that defect type class. Now, SDAS looks to see if there is any match between any of the list’s elements and the current manufacturing operation. In the current example, the software finds none. That is, there is no specific diagnosis file such as "ssawb" in the directory "ss", which would be the diagnosis information to supplement the generalized set of recommendations in the file "ss". The rule thereby fails at this list expansion and matching stage for rule 2(a).

SDAS proceeds to the lower priority rule in its queue. The matching conditions here are a simple subset of those of rule 2(a). Therefore rule 2(b) acts, in the transcript Section E, and causes the hypothesis Skipped_Stitch to be set to true. The generalized defect diagnosis file "ss" in the directory "ss" is displayed to the user, and the flag is set to indicate that the defect has been successfully analyzed. Other defect type rules are scanned in quick sequence and their hypotheses discarded.

Finally, the group of specification display rules acts and queries the user to see if the relevant set of norms and recommendations from the construction specifications need to be displayed. This is done by the question associated with atom View_Spec. If the user answers in the affirmative, the rules begin by synthesizing the name of the group of construction specifications from the Manufacturing Operation determined earlier in Level One processing. As in Section F of Figure
9.1b, this is assigned to the slot ‘Curr_Defect.Construction_Spec_Group’, and all the specification entries (objects in the class with the specification’s Name) are labelled as operationally relevant.

Another rule then checks these objects, each representing a specification declared as currently of interest, to see if the specification is of interest to the user. This is done by checking the Operationally_Relevant_Spec slot of the spec objects. These slot values are directly set by the user in the knowledge base. All the relevant specifications are concatenated by calling a C function and then displayed by SDAS.

Another Example: Figure 9.2 shows the two levels of rules used for illustrating the second example, namely, where the user sees an Open Seam at the double-lapped join of the crotch seam. The symmetry between the defect location and type rules seen in Figures 9.1a and 9.2 is readily apparent. This greatly helps modularity and ease of future modifications and enhancements. Also, the rules for defect location (which will be subject to the greatest flux, e.g., new rules for new garments) and those for defect type identification and analysis are completely compartmentalized.

The Level One rules work precisely as before, using the user-supplied location of "Crotch-Seam". The pattern matching commences and discards location hypotheses till a rule trying to assert the "Join_Crotch_Seam" hypothesis is encountered. All the LHS clauses prove correct, and this hypothesis is confirmed. (In fact, the pattern matching task is even easier than in the previous example, where there were three rules attempting to localize the defect somewhere on the waistband assembly). Since only one manufacturing operation could be responsible for an assembly operation defect such as an Open Seam, the ‘Curr_Defect.Mfg_Operation’ is filled with the data "Join_Crotch_Seam". Every member of the class of specifications from MIL-STD-87062A dealing with this operation is also marked as being of interest. A flag is set to inform other rule subsets within SDAS that the current defect’s location has been correctly absorbed. The system then discards all other defect location possibilities.

The Open Seam defect hypothesis is provable by two rules at the second Level (Figure 9.2). Since the more specific rule for this defect hypothesis has a higher priority, it will act first. On the LHS of the rule, the first two conditional clauses are satisfied. The third conditional clause checks if any object belonging to the class Open_Seam matches the data filling the slot Curr_Defect.Mfg_Operation, i.e., "Join_Crotch_Seam". If there is a match, it signifies that there is specific information on the causes and remedies for an Open Seam defect at Crotch Seam location.

Unlike the previous example, a match is found; that is, there is an object whose specific_operation slot has the same contents "Join_Crotch_Seam". The name of this object is Open_Seam_Join_Crotch_Seam, and its op_code or slot contains data "jcs". The rule is therefore successful in confirming its hypothesis. The RHS actions are now commenced, the last of which will set a flag that will inform all subsequent processing of the completion of the diagnosis. (This also disables the general rule 2(b) for Open_Seam in Figure 9.2, which is waiting in the rule priority queue, because there is no use for it after this point).

The first RHS action assigns the "os" type code to the atom Curr_Defect. The next RHS action synthesizes an "Operation Vector", using the type code "os" and the operation code extracted from the list-matched object. In this case, the object is Open_Seam_Join_Crotch_Seam, and its
LEVEL 1: Rule ObservedDef_Waistband
If there is no evidence of Location_Found
And Curr_Defect.Location is "Crotch_Seam"
  Then Join_Crotch_Seam is confirmed.
And |Curr_Defect|.Mfg_Operation is set to "Join_Crotch_Seam"
And <|SpecClass_Join_Crotch_Seam|>.Admissible_Spec is set to TRU
And Location_Found is set to TRUE

LEVEL 2 (a): Rule Open_Seam_Def_In_Specific_Operation;
PRI= -100;
If Curr_Defect.Type is "Open_Seam"
And there is no evidence of Curr_Defect.Diagnosis_Done
And <|Open_Seam|>.specific_operation matches
Curr_Defect.Mfg_Operation
  Then Open_Seam is confirmed.
And |Courier_Defect|.type_code is set to "os"
And |Curr_Defect|.OpVector is set to
STRCAT(Curr_Defect.type_code, <|Open_Seam|>.op_code)
And "concat" is Executed
And "tempfile" is Shown (@KEEP=TRUE,@WAIT=FALSE)
And Curr_Defect.Diagnosis_Done is set to TRUE

LEVEL 2 (b): Rule Open_Seam_Defect
If Curr_Defect.Type is "Open_Seam"
there is no evidence of Curr_Defect.Diagnosis_Done
  Then Open_Seam is confirmed.
And "causes/os/os" is Shown (@KEEP=TRUE,@WAIT=FALSE)
And Curr_Defect.Diagnosis_Done is set to TRUE

Figure 9.2 Two Levels of Rules for an Open Seam when Joining the Crotch Seam
op\_code field or slot contains data "jcs". Therefore, the concatenation of these will result in a string "osjcs" in the slot OpVector of atom Curr\_Defect. An external procedure called concat is called to bring together the contents of the generalized diagnosis file "os" in the directory "os" as well as the contents of the file "osjcs", which is additional information concerned with Open Seams only at this operation of Joining Crotch Seams. The result is put into file "tempfile" which is then displayed by the next RHS action.

9.2 Speed and Size of SDAS

Just as in the case of FDAS, it is extremely important that SDAS' response be as fast as possible since it is to be used by the garment inspector on the shopfloor.

Response Time

It has an advantage over FDAS as it needs only two defect characteristics from the user, viz., defect type and defect location (as opposed to five characteristics required by FDAS). SDAS displays menus for user input of the defect's visual characteristics almost instantaneously. Most diagnosis sessions take 2-4 seconds after user input has been completed to display the analysis and recommendations. In case the user desires to see the MIL specs, the system displays them in 2-3 seconds. Even for defect subclasses where the system asks further questions to pinpoint the manufacturing process responsible for the defect, the overall session time is about 15-20\(^1\) seconds.

Size of the Knowledge Base

SDAS has fewer rules compared to FDAS: only 70 rules, including the ancillary control rules for writing defect information out to the database. This was accomplished by exploiting the rich pattern matching and logical operators available in Nexpert in conjunction with the class structure. There is a trade-off, however, in that the class-object hierarchy is complex.

9.3 Modularity and Ease of Customization

The diagnostics information is contained in text files, as in the case of FDAS. Hence, users can customize the system output to their requirements without affecting the working of the rest of the system. The directories containing the diagnosis files have been structured to exactly mimic the defects class structure. Hence, it is easy for the user to make modifications at the right place.

On the other hand, making modifications to the knowledge base itself requires more knowledge engineering when compared to FDAS. The basis of classification, viz., nature of the defect and the location of the defect are applicable to all garment types. However, since the possible locations are entirely different for different garment types, the defect class hierarchy will be different for different garments.

---

1. All the times mentioned are for the DOS version; the UNIX version takes slightly shorter times as all the data needed for the system are entered within a single form.
CHAPTER 10

DATABASE INTEGRATION WITH FDAS AND SDAS

FDAS and SDAS have knowledge about fabric and sewing defects and can help users in identifying a defect accurately and in taking appropriate remedial actions. In addition to these, there is a need to monitor long- and short-term trends in defect occurrences for effective quality control. To do this, data about defect occurrences is to be recorded in a database, which can be used for generation of reports in any required form. Information about defects is represented in the form of objects and object attributes in the knowledge bases. In a relational database, it has to be maintained in a table in the form of records and fields. Nexpert Object allows dynamic communication with databases by linking object attributes to fields in a table. Currently, FDAS and SDAS have been made to write data to an Oracle relational database. Nexpert Object can also be linked to a number of other flat-file and relational databases.

10.1 Database Schema

Figure 10.1a shows the database table used to record information about sewing defects. The first field (column) in the table identifies a defect occurrence uniquely and hence is called the key to the table. Starting from left, two digits each are used to represent the month, date, year, hour, minute and second at which the defect was recorded. For example, the first defect in the table was recorded in the month of January, on the 15th, in the year '92, at 12 minutes and 11 seconds past 8 a.m. The second field is the identification number assigned to the bundle and is an alpha-numeric string. This is useful in tracing the defect to the cut or bundle. The third field shows the part of the garment where the defect was found. This and the information in the last field, viz., type of the defect were volunteered by the user to SDAS. The fourth field shows the manufacturing operation which could have caused the defect. This information is the outcome of inferencing by SDAS. Defects can be sorted on any of the fields and summary data can be generated. For example, the database can be queried for defect occurrences due to a particular manufacturing operation or on defects of a particular type.

The database table for FDAS is shown in Figure 10.1b. The time of occurrence is again used as the key. Other information contained in the database are the style number of the fabric, the descriptive name of the defect, and the direction of occurrence of the defect (length, width or no preferred orientation).

10.2 Communication with the Database

Writing information to the database is triggered by rules in the knowledge base. Figure 10.2a shows the two rules in SDAS leading to the recording of defects data. The first condition for Rule 19, Curr_Defect-diagnosis_Done, is set to true by rules which identify different individual defects (e.g., Level 2 (a) in Figure 9.2). At the beginning of a session, the user is asked if defect information is to be written to the database. If the user had answered in the affirmative, the second condition, DBtransact-writeflag would have been set to true. Once these two conditions are satisfied, Get_curr_time is set to true, which in turn causes Rule 14 to fire. Also
<table>
<thead>
<tr>
<th>TIMEDATE</th>
<th>BUNDLE-ID</th>
<th>DEF_LOCATION</th>
<th>MFG_OPERATION</th>
<th>DEF_TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>011592081211</td>
<td>DT149725</td>
<td>BELT_LOOP</td>
<td>ATTACH_BELT_LOOP</td>
<td>BROKEN_THREAD</td>
</tr>
<tr>
<td>011592092319</td>
<td>BX229374</td>
<td>PATCH-POCKET</td>
<td>MAKE_PATCH_POCKET</td>
<td>OPEN_SEAM</td>
</tr>
</tbody>
</table>

Figure 10.1a Database Table for SDAS

<table>
<thead>
<tr>
<th>TIMEDATE</th>
<th>STYLE_NUM</th>
<th>DEF_DESC</th>
<th>DEF_DIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>122391112416</td>
<td>HD152944</td>
<td>COARSE_YARN</td>
<td>WARP</td>
</tr>
<tr>
<td>122391121734</td>
<td>BG598423</td>
<td>THICK_PLACE</td>
<td>FILLING</td>
</tr>
</tbody>
</table>

Figure 10.1b Database Table for FDAS
RULE : Rule 19
If
there is evidence of Curr_DefectDiagnosis_Done
there is evidence of DBtransact.writeflag
Then
Get_curr_time is confirmed.
And Execute "timestamp"()

RULE : Rule 14
If
there is evidence of Get_curr_time
Then
Database_Trigger is confirmed.
And <|FabricDefects|>.Type assigned to CurrDef.ObsName
And Writing in
"@V(DBtransact.username)@V(DBtransact.userpassword)"
@TYPE=ORACLE;@FILL=ADD;@END="COMMIT";@NAME="!TIMEDATE!"
@PROPS=Time_and_Date,OpVector,Location,Mfg_Operation,
Type;
@FIELDS="TIMEDATE","BUNDLE_ID","DEF_LOCATION",
"MFG_OPERATION","DEF_TYPE";
@QUERY="SEW_DEF";@ATOMS=CurrDef;

Figure 10.2a Rules for Accessing the Database from SDAS

RULE : Rule 176
If
there is no evidence of Diagnosis_Pending
there is evidence of DBtransact.writeflag
Then
Get_curr_time is confirmed.
And Execute "timestamp"()

RULE : Rule 154
If
there is evidence of Get_curr_time
Then
Database_Trigger is confirmed.
And <|FabricDefects|>.Type assigned to CurrDef.ObsName
And Writing in
"@V(DBtransact.username)@V(DBtransact.userpassword)"
@TYPE=ORACLE;@FILL=ADD;@END="COMMIT";@NAME="!TIMEDATE!"
@PROPS=ObsType,ObsName,ObsDir,Time_and_Date;
@FIELDS="STYLE_NUM","DEF_DESC","DEF_DIR","TIMEDATE";
@QUERY="FAB_DEF";@ATOMS=CurrDef;

Figure 10.2b Rules for Accessing the Database from FDAS
the function "timestamp" is executed, which forms the "TIMEDATE" string in a form described in the previous section.

Rule 14 has a list of knowledge base properties (following @PROPS=) which are to be recorded in a database, and another list of the fields in the database table (following @FIELDS=) which will hold these properties. The elements of the two lists have one-to-one correspondence. The name of the database table, viz., "SEW_DEF," is shown as the value of @QUERY and that of the atom whose properties are to be recorded is shown as the value of @ATOMS. "@TYPE=ORACLE" sets the database type; "@FILL=ADD" causes new records to be added to the end of the table; "@END="COMMIT"" instructs the database management system to write the record permanently (commit) once the transaction is complete; and "@NAME="!TIMEDATE!"" indicates that TIMEDATE is the key to the table SEW_DEF. "DBtransact.username" is the user-id and "DBtransact.userpassword" is the password for the user, and these must have been set by the database administrator.

For FDAS, a similar scheme is used to write information to a database table called FAB_DEF (Figure 10.1b). The rules triggering this process are shown in Figure 10.2b.
CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions that can be drawn from the research carried out and discussed in the previous chapters. Recommendations for further development work on FDAS and SDAS are also presented.

11.1 Conclusions

Two separate knowledge-based systems -- FDAS and SDAS -- have been developed for analysis of denim fabric and utility trouser manufacturing defects, respectively. In addition to being useful for analysis of defects, these systems will be effective tools to train fabric and garment inspectors and other quality control personnel.

Both the systems employ novel schemes for classifying defects, based only on the visual attributes of the defects. The important advantage of these schemes is that they do not require prior knowledge of the defect. Consequently, the scheme can be used as an underlying framework for an automatic (vision-based) fabric inspection system.

FDAS identifies a defect uniquely after a five- or six-stage search process. The system response is fast and is not expected to delay the operator's task on the shopfloor. SDAS identifies a defect after a two- or three-stage search process and is also fast in its response.

Both the systems can be easily tailored for the special needs of any individual organization as the diagnosis information can be altered independently of the remainder of the system. Other system design objectives such as flexible user interface and effective separation of domain and control knowledge have also been achieved.

The systems have been extensively tested in-house and have been demonstrated to experts, and they are ready for in-plant testing.

11.2 Recommendations

Both knowledge bases have been designed to accommodate extensions to other product types. Extension of FDAS to analyze other fabrics (besides denims) will not only be useful, but also can be accomplished without many changes to the current knowledge base. Likewise, the scope of SDAS can be broadened to other garments (besides utility trousers).

FDAS should be tested as a backend to vision-based defect detection systems, such as the one recently announced by ELBIT Vision Systems of Israel.

Attempts have been made to keep the verbal description of defects easy to understand by using a consistent description scheme with limited number of attributes. However, a pictorial rep-
representation of defects is expected to reduce possible ambiguities associated with verbal descriptions. This task requires collection of fabric defect samples and developing means to display both the fine details, such as appearance, and global details, such as orientation and pattern of repeat, on a computer terminal.

Both the systems should be tested in textile/apparel plants.
BIBLIOGRAPHY


Haupverband Baumwollweberei, "Gewebefehler - Bezeichnungen und Definitionen," Deutscher Verlag, GmbH, Frankfurt, Germany.


[KDS] KDS KDS Corp., 934 Hunter Rd., Wilmette, IL 60091; (312) 251-2621.


[Know] Knowledge Craft Carnegie Group, Inc., 650 Commerce Court. Station Square, Pittsburgh, PA 15219; (412) 642-6900.


[PC+] Personal Consultant+ (PC+) Texas Instruments, Inc., PO Box 209, MS 2151, Austin, TX 78769; (800) 527-3500.


[S.1] S.1 Teknowledge, Inc., 1850 Embarcadero Rd., PO Box 10119, Palo Alto, CA 94303; (415) 424-0500.


APPENDIX A

Defects Questionnaires
Dear AAMA Member:

Our Association is pleased to support two research projects currently in progress at Georgia Tech under the direction of Dr. Sundaresan Jayaraman for the U.S. Defense Logistics Agency. As you can see from the enclosed background papers, these projects are of considerable interest to our community and we will stand to benefit from them. The researchers have developed three questionnaires for these projects and are looking to our industry for information and input.

The first project is in the area of defects in apparel manufacturing and there are two questionnaires for this project. The short one is for an overall economic assessment of defects, while the long one is for a detailed analysis of defects. They can best be answered by quality control and/or manufacturing personnel.

The second project is in the area of contractor evaluation and there is one questionnaire for this project. It can best be answered by your contracting personnel.

If your firm is not experienced in either matter, please discard these surveys. If your experience and input might be beneficial to the research study, please have knowledgeable individuals from your firm complete the surveys and return them directly to the address given below. The enclosed background papers will help the individuals in responding to the surveys. If you have any questions on the projects, please feel free to call Sundaresan at 404/894-2490.

Your cooperation in these studies is greatly appreciated. Please return the surveys before September 6, 1989 to

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
Fax: 404/894-8780

Cordially,

[Signature]

Director of Technical Services

2500 Wilson Boulevard/ Suite 301/ Arlington, Virginia 22201 • 703/524-1864 • FAX 703/522-6741
ANALYSIS OF DEFECTS IN APPAREL MANUFACTURING

QUESTIONNAIRE

AUGUST 1989

Please note: Neither your name nor that of your company will be published or released to anyone. All the information will be used for analysis only.

Please return the questionnaire to:

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Tel: 404/894-2490
FAX: 404/894-8780
Research Background

Quality is free and defects cost money. Georgia Tech has undertaken research in the School of Textile Engineering aimed at developing a knowledge-based system for the analysis of defects in apparel manufacturing. A knowledge-based framework (commonly referred to as an expert system) is an intelligent computer program that will assist apparel manufacturers in identifying the sources for the various types of defects (e.g., fabric, sewing) and the remedies for minimizing them. The key to the development of such a system is the knowledge base, i.e., the criteria, rules and scheme used for the classification and prevention of defects. Yet another objective of the research endeavor is to assess the economic impact of defects in apparel manufacturing, i.e., the loss of sales due to second quality garments and loss of productive time due to reworking.

The Questionnaire

The purpose of the enclosed questionnaire is to solicit your expert opinion on defects in garment manufacturing based on your experience. The listed questions may miss some points that you feel are important. You are invited to correct this by adding comments freely. Your input is extremely valuable and urgently needed.

In return for your help, you will be offered the opportunity to receive a copy of the results of the questionnaire. The computer programs can also be made available to you and your company for your use. See the end of the questionnaire for more details. Also, if another person in your organization can offer their experience to this questionnaire, please notify us to secure additional copies or copy this one for them. Thank you for assisting us in reaching as many experts as is possible.

Research Sponsor

This research is being sponsored by the Defense Logistics Agency (DLA) in the Department of Defense. The DLA procures approximately $1.6 billion worth of apparel every year and is funding this research to promote the production of quality goods and to enhance the overall state of the textile and apparel industries in the United States.

Confidentiality of Information

The researchers recognize the importance of the information furnished by you. The information will be utilized for research purposes only and the company name will be kept confidential.
1. This Questionnaire is designed to seek information on defects encountered in the apparel manufacturing process, specifically, trouser manufacturing. If you are not a trouser manufacturer, please identify below the major product of your company and fill in information only for this product.

Information furnished is for product (e.g., shirts, lingerie, etc.): ________________

2. CLASSIFICATION OF DEFECTS: The following example illustrates one way of classifying defects found in assembled garments. This example, in fact, is a strict reproduction of the classification scheme outlined in the military standard, MIL-STD-105D and used extensively for government and military procurement purposes.

DEFECTS IN ASSEMBLED GARMENTS

<table>
<thead>
<tr>
<th>CRITICAL</th>
<th>MAJOR</th>
<th>MINOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A critical defect is one that could lead to hazardous and unsafe conditions during usage.</td>
<td>A major defect is one that is essentially non-critical but could result in premature failure or in reduced life.</td>
<td>A minor defect is one that does not materially reduce the usability of the product nor will it have a significant effect on the use or operation of the product.</td>
</tr>
<tr>
<td>Examples: Inadequate flame retardancy, toxic finish, etc.</td>
<td>Examples: Two or three skipped or broken stitches, visible hole or holes in the garment, etc.</td>
<td>Examples: Occasional skipped or broken stitch, slightly irregular stitch gauge, etc.</td>
</tr>
</tbody>
</table>

A. Use the above illustration as an example and list the broad categories into which defects in assembled trousers (or your major product) are classified in your own organization. For each category you use, clearly state the factors or criteria that are used to assign defects to that category. If you use a Point System, please list each point value under "category" and list the factors or criteria that determine their assignment.

If you already have this information in printed form, please insert a copy here and go on to section B (page 5). If you do not classify defects at all, skip to Question 3 (page 7).
<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
B. For each category you identified above, please list all the individual defects that fall within that category.

If you already have the necessary information in printed form, simply insert it here in the questionnaire and go on to Question 3.

<table>
<thead>
<tr>
<th>Category</th>
<th>Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Defects</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. **RAW MATERIAL TESTING:**

A number of properties of fabric and trim are listed below. Note that there are five groups of properties -- one each for fabric, thread, buttons, zippers, and lining materials. For each property in each group, please answer the following queries:

a. Do you specify this property when you place the order?

b. Do you physically test the fabric or trim for this property when it arrives? If you do not test fabric or trim for this property, skip to the next property.

c. What is your average lot size (e.g., 1,000 yards of fabric, a gross of buttons)?

d. When you test for this property, what is your average sample size per lot? Please be specific about the unit of measure (e.g., 5 yards per bolt, 10 buttons per gross).

e. What is the standard value for this property?

f. What is an acceptable tolerance for this property? Please specify this in either units (e.g., 5 yards per thousand) or percent.

Please use an "X" mark in the parentheses, to indicate YES, in the appropriate column. Fill in the blanks in the other columns. If you use an ASTM standard for testing of a property, please specify the test number in the last column.

### FABRIC

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specified In Order</th>
<th>Physically Tested</th>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Std. Value</th>
<th>Tolerance</th>
<th>ASTM number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ends/Picks</td>
<td>( )</td>
<td>( )</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Weave</td>
<td>( )</td>
<td>( )</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Weight</td>
<td>( )</td>
<td>( )</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Thickness</td>
<td>( )</td>
<td>( )</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Finish</td>
<td>( )</td>
<td>( )</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Width</td>
<td>( )</td>
<td>( )</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Fabric Properties (cont.)</td>
<td>Specified In Order</td>
<td>Physically Tested</td>
<td>Lot Size</td>
<td>Sample Size</td>
<td>Std. Value</td>
<td>Tolerance</td>
<td>ASTM number</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------</td>
<td>-------------------</td>
<td>----------</td>
<td>-------------</td>
<td>------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>Color/Shade Fastness</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crease Resistance</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilling Resistance</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crock Fastness</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tensile</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tearing</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bursting</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abrasion Resistance</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural Rigidity</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Permeability</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wash and Wear Performance</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any Other Fabric Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## THREAD

<table>
<thead>
<tr>
<th>Properties In Order</th>
<th>Specified In Order</th>
<th>Physically Tested</th>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Std. Value</th>
<th>Tolerance</th>
<th>ASTM num-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blend</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Count</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Twist</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Ply</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Color Fastness</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Strength:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>loop</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>tensile</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Elongation</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Twist</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Liveliness</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>

## BUTTON

<table>
<thead>
<tr>
<th>Properties In Order</th>
<th>Specified In Order</th>
<th>Physically Tested</th>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Std. Value</th>
<th>Tolerance</th>
<th>ASTM num-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Heat Resistance</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Water Resistance</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Color Fastness</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Weight</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Shape Uniformity</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>
### ZIPPER

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specified In Order</th>
<th>Physically Tested</th>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Std. Value</th>
<th>Tolerance</th>
<th>ASTM num-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Resistance</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Resistance</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color Fastness</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycles to Failure</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### LINING MATERIALS

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specified In Order</th>
<th>Physically Tested</th>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Std. Value</th>
<th>Tolerance</th>
<th>ASTM num-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Blend Composition</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction (Woven or Nonwoven)</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tensile</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tear</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breaking Elong.</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural Rigidity</td>
<td>( )</td>
<td>( )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MISCELLANEOUS

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specified</th>
<th>Physically Tested</th>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Std. Value</th>
<th>Tolerance</th>
<th>ASTM num.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ber</td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td></td>
<td>( )</td>
<td>( )</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>

4. TYPES OF FABRICS USED: Below are listed the major types of primary (shell) and lining fabrics -- wovens, nonwovens and knits. For each type of fabric, please indicate:

i. What **percentage** of the fabric you purchase is of each type?

ii. What is the **average cost per yard** for each?

iii. What **percentage** of the yardage you purchase represents each of the fiber types indicated?

## PRIMARY FABRICS

<table>
<thead>
<tr>
<th>FABRIC TYPE</th>
<th>% OF PURCHASES</th>
<th>AVG. $/YD</th>
<th>WOOL</th>
<th>SYNTHETICS</th>
<th>COTTON</th>
<th>BLENDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wovens</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Knits</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>

## LINING FABRICS

<table>
<thead>
<tr>
<th>FABRIC TYPE</th>
<th>% OF PURCHASES</th>
<th>AVG. $/YD</th>
<th>FIBER TYPE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wovens</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Nonwovens</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>
5. **RAW MATERIAL DEFECTS:** A number of defects in raw materials are listed below. For each defect listed, please answer the following:

i. What percentage of the material you inspect contains this defect? Include only defective material that is identified during the raw materials inspection stage. If you do not inspect raw materials, skip to Question 6.

ii. What is your best estimate of the total dollar loss due to this defect in 1988, at the raw material inspection stage? If you cannot estimate the dollar amount, please rank the extent of the monetary loss on a scale from one to five, where one means "An Insignificant Loss" and five means "A Very Significant Loss".

Please list any other defects in raw materials that may not be included below and provide similar information for these defects as well.

**FABRIC DEFECTS**

<table>
<thead>
<tr>
<th>DEFECTS</th>
<th>VALUE LOSS DUE</th>
<th>DEFECTS AS A % OF TOTAL MATERIAL INSPECTED</th>
<th>VALUE LOSS DUE TO MATERIAL DEFECTS ($/YEAR)</th>
<th>INSIGNIFICANT LOSS</th>
<th>VERY SIGNIFICANT LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color variation (per yd.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- side to side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- yard to yard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- lot to lot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible defects (per yd.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- holes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- stains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- missing threads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- warp streaks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- filling defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- spot defects (slubs, nepds, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- bad selvage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- pilling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- reed marks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- mixed ends</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width variation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- yard to yard (per yd)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- roll to roll</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improper finish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- poor hand (per yd)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- printing defects (if applicable)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. **FINISHED GOODS DEFECTS**: A number of defects in finished goods are listed below. They are organized into four groups - manufacturing defects, material defects, trim defects, and miscellaneous defects. For each defect listed, please answer the following:

i. What percentage of the finished goods you inspect contains this defect? Include only defective items that are identified during the finished goods inspection stage. If you do not inspect finished goods, skip to Question 6.

ii. What is your best estimate of the total dollar loss due to this defect in 1988, at the finished goods inspection stage? If you cannot estimate the dollar amount, please rank the extent of the monetary loss on a scale from one to five, where one means "An Insignificant Loss" and five means "A Very Significant Loss".
Please list any additional defects in finished goods that are not included below and provide similar information.

<table>
<thead>
<tr>
<th>MANUFACTURING DEFECTS</th>
<th>DEFECTS AS A % OF TOTAL UNITS PRODUCED</th>
<th>VALUE LOSS DUE TO MANUFACT. DEFECTS ($) / YEAR</th>
<th>INSIGNIFICANT LOSS</th>
<th>VERY SIGNIFICANT LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreading Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- tight or slack, incor-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rect overlap, etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- improper folds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- wrong side up</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutting defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- frayed edges</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fused or scorched</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>edges</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ragged, serrated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or fuzzy edges</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- improper size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- improper notches</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rips or pulled yarns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- incorrect bundle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>identification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- skipped stitches</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- stitching distortion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(packering, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- improper stitch size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- yarn severance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- improper stitch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>width, letout</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- seam slippage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- other (specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soiled garments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressing Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fusion or scorching</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- shine due to mechani-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cal pressure of the</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>contacting ram buck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Defective Pockets
- misaligned/misplaced
- other (specify)

## Fit / Form
- incorrect size
- incorrect plaid or stripe matching
- poor drape

## Shrinkage
- poorly finished
  or stitched
- twisted legs

## Leg bottom
- poorly finished
  or stitched
- twisted legs

## Defects in:
- belt loops
- fly
- button holes

## Incorrect size tickets

### Fabric Defects

<table>
<thead>
<tr>
<th>DEFECTS AS A % OF TOTAL UNITS PRODUCED</th>
<th>VALUE LOSS DUE TO FABRIC DEFECTS ($ / YEAR)</th>
<th>INSIGNIFICANT LOSS</th>
<th>VERY SIGNIFICANT LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color Variation</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- side to side</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- yard to yard</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- batch to batch</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Visible defects</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- holes</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- stains</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- missing threads</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- warp streaks</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- filling defects</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>- spot defects</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>(slubs, nep, etc.)</td>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>
### FABRIC DEFECTS (cont.)

<table>
<thead>
<tr>
<th>Defects</th>
<th>% of Total Units Produced</th>
<th>Value Loss Due to Fabric Defects ($/Year)</th>
<th>Insignificant Loss</th>
<th>Very Significant Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilling</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Reed marks</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Mixed ends</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Width variation</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Yard to yard</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Batch to batch</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Improper finish</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Poor hand</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Not meeting specs for water repellency, etc.</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Printing defects</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>

### TRIM DEFECTS

<table>
<thead>
<tr>
<th>Defects</th>
<th>% of Total Units Produced</th>
<th>Value Loss Due to Trim Defects ($/Year)</th>
<th>Insignificant Loss</th>
<th>Very Significant Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buttons broken/poor strength</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Buttons of wrong color</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Bad zippers</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Bad pockets</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Other (specify)</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>

### MISCELLANEOUS DEFECTS

<table>
<thead>
<tr>
<th>Defects</th>
<th>% of Total Units Produced</th>
<th>Value Loss Due to All Other Defects ($/Year)</th>
<th>Insignificant Loss</th>
<th>Very Significant Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>(please specify)</td>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>
7. INFORMATION ON QUALITY CONTROL PERSONNEL

i. What is the title of the person who is responsible for fabric/trim inspection?

ii. How many hours of formal classroom training did they receive? How many hours of on-the-job-training (OJT) did they receive?

   Classroom hours

   OJT hours

iii. What is the title of the person who is responsible for categorizing defects in finished garments?

iv. On average, in your plant, how many years of experience in finished garment inspection does this individual have?

   _________ years

v. Does this person usually have previous experience as a sewing machine operator?

   (Y/N) ___________

vi. How many hours of formal classroom training did they receive? How many hours of on-the-job-training did they receive?

   Classroom hours

   OJT hours
8. **ECONOMIC IMPACT OF DEFECTS:** Some specific details related to the economic impact of defects are sought below:

i. Please list the categories into which defective garments are classified for the purpose of selling and disposal (e.g., seconds, rags, etc.).

ii. Indicate the approximate percentage of garments that fall into each defect category.

iii. Estimate the discount by which you mark down these defective garments as compared to first quality garments.

If you do not classify defective garments into different categories for selling purposes, explain how exactly you dispose of these products and state the average value loss suffered on the defective products as a whole.

<table>
<thead>
<tr>
<th>CATEGORY OF DEFECTIVE GARMENT</th>
<th>% OF TOTAL UNITS PRODUCED</th>
<th>% DISCOUNT VS. FIRST QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
COMPANY AND PERSONAL INFORMATION

Neither your name nor that of your company will be published or released to anyone. All the information will be used for analysis only. The following questions deal with information about yourself and your company:

1. Over the past two years, what were the major types (shirts, trousers, skirts, etc.) of garments produced by your company?

2. For each of these classes of garments, please indicate the percentage of your total production volume that these represent.

<table>
<thead>
<tr>
<th>Type of garment</th>
<th>% of total production volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Company size in annual sales: $_______, # units:_______

4. Number of employees:

   Production:__________

   Production Support:__________

   Administrative Support:__________

   Management:__________

5. What garments have you, personally, had experience manufacturing -- regardless of where you gained this experience? (shirts, trousers, etc.):

6. How long have you been involved in apparel manufacturing?

   ___________ years.
SURVEY PARTICIPATION AND BENEFITS

i.) Would you like to receive a copy of the survey results? (Y or N) _________

ii.) Would you be willing to participate in a telephone discussion on this topic? (Y or N) _________

iii.) Would you be willing to attend a group seminar to discuss this topic, assuming a suitable site is found? (Y or N) _________

iv.) Would you be willing to serve on our panel of experts? (This would require that you attend three meetings each year in Atlanta.) (Y or N) _________

v.) Would you be willing to serve as a test site for the software program for analyzing apparel defects while it is in its prototype stage of development? (Y or N) _________

CONFIDENTIALITY

If you answered yes to any of i.) through v.), then we will need your name and address. We would like to know who you are anyway, perhaps because your response may need further clarification in a personal call. Neither your name nor that of your company will be published or released to anyone.

THIS IS CONFIDENTIAL INFORMATION

NAME _______________________________ TITLE __________

COMPANY ____________________________

ADDRESS ____________________________

CITY, STATE, ZIP ________________________ ____ ______

TELEPHONE (_____) ______-_________
GEORGIA TECH CONTACTS FOR MORE INFORMATION

If you have any questions or need additional information on the questionnaire, please feel free to contact us:

Project Principal Investigator:

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0295

ph. (404) 894-2461 or 894-2490 (sec’y)

Research Investigators

Dr. Krishna Parachuru
(address same)

Dr. Phiroze H. Dastoor
(address same)

ph. (404) 894-2494 or 894-2490

THANK YOU FOR YOUR TIME AND EFFORT
ECONOMIC IMPACT OF DEFECTS IN APPAREL MANUFACTURING

QUESTIONNAIRE

AUGUST 1989

Please note: Neither your name nor that of your company will be published or released to anyone. All the information will be used for analysis only.

Please return the questionnaire to:

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Tel: 404/894-2490
FAX: 404/894-8780
1) List three major garment types produced by your company during the past production year. If your company produced only one type of garment, please ignore product numbers (ii) and (iii) listed under Questions 1-5.

<table>
<thead>
<tr>
<th>Product No.</th>
<th>Product Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td></td>
</tr>
<tr>
<td>ii</td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td></td>
</tr>
</tbody>
</table>

2) For each of the products identified above, give the total number of first and seconds quality garments (or, percentages of first and seconds quality garments) turned out during the past production year.

<table>
<thead>
<tr>
<th>Product No.</th>
<th>No. of First Quality Products</th>
<th>No. of Seconds Quality Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3) Give the figures of average price realization (selling price per piece) for the first and seconds quality products.

<table>
<thead>
<tr>
<th>Product No.</th>
<th>Selling Price of First Quality Products</th>
<th>Selling Price of Seconds Quality Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4) Do you believe that the percentage of seconds quality products turned out by your company is in tune with overall industry standards?

_____ Yes  _____ No

If ‘No’, please indicate the industry standards for the percentage of seconds quality products.

<table>
<thead>
<tr>
<th>Product No.</th>
<th>Industry Standards for the Percentage of Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td></td>
</tr>
<tr>
<td>ii</td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td></td>
</tr>
</tbody>
</table>

5) What percentage of total defects do you believe can be attributed to the two principal sources, namely, fabric quality and sewing performance?

<table>
<thead>
<tr>
<th>Product No.</th>
<th>Percentage of Defects Attributable to Fabric Deficiencies</th>
<th>Percentage of Defects Attributable to the Cutting &amp; Sewing Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
COMPANY AND PERSONAL INFORMATION (will be kept confidential)

1. Name: ____________________________  Title: ____________________________
   Company: ____________________________  Telephone: ____________________________
   Address: ____________________________
   City, State, Zip: ____________________________

2. Company size in annual sales: $ ____________,  # units: ____________

3. Number of employees:
   Production: ____________
   Production Support: ____________
   Administrative Support: ____________
   Management: ____________

GEORGIA TECH CONTACTS FOR MORE INFORMATION

If you have any questions or need additional information on the questionnaire, please feel free to contact us:

Project Principal Investigator:

   Dr. Sundaresan Jayaraman
   School of Textile Engineering
   Georgia Institute of Technology
   Atlanta, Georgia 30332-0295

   ph. (404) 894-2461 or 894-2490 (sec’y)

Research Investigators

   Dr. Krishna Parachuru
   Dr. Phiroze H. Dastoor
   (address same)

   ph. (404) 894-2494 or 894-2490

THANK YOU FOR YOUR TIME AND EFFORT
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING: DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK

Volume II: FDAS User Manual

Research sponsored by

Defense Logistics Agency
DLA-PRM
Cameron Station
Alexandria, Virginia

DLA Contract #: DLA-900-87-D-0018-0003

Reported by:

Dr. Sundaresan Jayaraman
Principal Investigator

Georgia Institute of Technology
School of Textile & Fiber Engineering
Atlanta, GA 30332-0295

Tel: 404-894-2490
Fax: 404-894-8780

Georgia Tech Project #: E-27-637

November 1988 - November 1991

SJ-TR-DEFE-9202
Research has been carried out to analyze defects in apparel manufacturing. Two knowledge-based software systems -- FDAS (Fabric Defects Analysis System) and SDAS (Sewing Defects Analysis System) -- have been developed. The research has been funded by the U.S. Defense Logistics Agency under contract number DLA-900-87-D-0018-0003.

FDAS covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. SDAS covers the defects occurring in the cutting, sewing, finishing and packing departments of an apparel plant producing denim trousers. Based on the visual description of the defect in the fabric (type, orientation and mode of repetition of the defect), FDAS identifies the defect and suggests possible causes and remedies.

(Continued on reverse)
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING:
DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK

Volume II: FDAS User Manual

Research sponsored by
Defense Logistics Agency
DLA-PRM
Cameron Station
Alexandria, Virginia

DLA Contract #: DLA-900-87-D-0018-0003

Reported by:
Dr. Sundaresan Jayaraman
Principal Investigator

Georgia Institute of Technology
School of Textile & Fiber Engineering
Atlanta, GA 30332-0295

Tel: 404-894-2490
Fax: 404-894-8780

Georgia Tech Project #: E-27-637

November 1988 - November 1991

SJ-TR-DEFE-9202
Research Project Personnel

K. Srinivasan
Graduate Research Assistant

Dr. Krishna Parachuru
Dr. Phiroze H. Dastoor
Research Investigators

Dr. Sundaresan Jayaraman
Principal Investigator
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>iv</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 What is FDAS?</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Working Principle of FDAS</td>
<td>1</td>
</tr>
<tr>
<td>1.3 Scope and Applications of FDAS</td>
<td>1</td>
</tr>
<tr>
<td>1.4 Requirements From the User</td>
<td>3</td>
</tr>
<tr>
<td>2. OPERATIONAL DESCRIPTION</td>
<td>4</td>
</tr>
<tr>
<td>2.1 Starting Up FDAS</td>
<td>4</td>
</tr>
<tr>
<td>2.2 Defect Analysis</td>
<td>4</td>
</tr>
<tr>
<td>2.2.1 Input of defect type</td>
<td>4</td>
</tr>
<tr>
<td>2.2.2 Input of defect direction/extent</td>
<td>5</td>
</tr>
<tr>
<td>2.2.3 Input of lengthwise repeat pattern</td>
<td>6</td>
</tr>
<tr>
<td>2.2.4 Input of widthwise repeat pattern</td>
<td>7</td>
</tr>
<tr>
<td>2.2.5 Identification of defect</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Diagnosis Capability of the System</td>
<td>8</td>
</tr>
<tr>
<td>3. SAMPLE SESSIONS</td>
<td>10</td>
</tr>
<tr>
<td>3.1 Point Defect</td>
<td>10</td>
</tr>
<tr>
<td>3.2 Line Defect</td>
<td>16</td>
</tr>
<tr>
<td>3.3 Area Defect</td>
<td>22</td>
</tr>
<tr>
<td>4. ERROR HANDLING BY FDAS</td>
<td>26</td>
</tr>
<tr>
<td>4.1 Failure Type 1</td>
<td>26</td>
</tr>
<tr>
<td>4.2 Failure Type 2</td>
<td>27</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Research has been carried out to analyze defects in apparel manufacturing. Two knowledge-based software systems -- FDAS (Fabric Defects Analysis System) and SDAS (Sewing Defects Analysis System) -- have been developed. The research has been funded by the U.S. Defense Logistics Agency under contract number DLA-900-87-D-0018-0003.

FDAS covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. SDAS covers the defects occurring in the cutting, sewing, finishing and packing departments of an apparel plant producing denim trousers. Based on the visual description of the defect in the fabric (type, orientation and mode of repetition of the defect), FDAS identifies the defect and suggests possible causes and remedies.

SDAS uses information on the location and nature of the defect to identify the manufacturing operation causing the defect and displays possible causes and remedies for the defect. SDAS also has a provision to display the relevant construction specifications (MIL-SPEC) for the assembly operation causing the defect. Both FDAS and SDAS are implemented in Nexpert Object and are linked to a relational data base using Oracle. They run under both MS-DOS and Unix environments. Software manuals for using FDAS and SDAS have been produced.

FDAS is intended for use at the greige or finished fabric inspection station in a weaving plant. It can also serve as a backend to a vision-based inspection system. SDAS can be used by an apparel plant for the inspection of trousers.

About the Report: The final technical report is presented in three volumes. In Volume I, the details of the research effort are discussed along with recommendations for additional research. Volume II (the present volume) is the software user manual for FDAS, while Volume III is the software user manual for SDAS.
1. INTRODUCTION

1.1 What is FDAS?

FDAS (Fabric Defects Analysis System) is an identification and diagnosis system for defects encountered in woven fabrics. The system covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. The development of the system has been funded by the U.S. Defense Logistics Agency.

1.2 Working Principle of FDAS

The flowchart in Figure 1 summarizes the working of FDAS.

First, FDAS assembles information about the current defect, as seen by the user. The user indicates a few salient visual features of the defect such as defect type, orientation, and mode of repetition along warp and filling directions. After receiving information on the visual characteristics of the defect, the software compiles a list of all possible fabric defects that share the particular visual description. The system presents a precise description of each individual defect in this group, and allows the user to decide which description exactly matches the defect under review. This matching of defect description with the actual defect is the final step in the identification process. The software then displays an analysis of the defect by listing the possible causes and remedies.

1.3 Scope and Applications of FDAS

In its present form, FDAS is ideally suited for indigo-dyed denim fabrics. However, the system can be used by any weaving or finishing plant because it has the knowledge for the analysis of defects occurring in these processes. Classification and analysis of defects on a day-to-day basis will be helpful in maximizing the percentage of first quality production. The system can be located at the greige or finished fabric inspection station or at the tenter frame to record and classify defect occurrences on a continuous production basis.

FDAS is linked to a database program; so it can be used to keep track of defect occurrences and initiate remedial action when required, e.g., whenever a particular defect type or the overall percentage of defective products exceeds pre-set threshold levels. Database software will also simplify report generation and quality monitoring of the different fabric sorts and styles in production.
Obtain information on the visual features of the defect

Compile the list of defects sharing the particular set of visual features

Is the number of defects > 8?

Yes

Find a defects sub-group based on additional information provided by the user

No

Assist the user in obtaining a match between the actual defect and one of the defect descriptions

Display defect identification and a list of probable causes and remedies

Figure 1. Flowchart for the Analysis of a Single Defect
1.4 Requirements From the User

To make efficient use of FDAS, the user should possess a basic understanding of the system. It is very important to remember that FDAS is an aid for the classification and analysis of fabric defects and not a replacement for a sharp-eyed and experienced inspector.

The learning time depends on the background and education level of the user but is not expected to be more than a day or two at most. An average high school graduate with basic analytical skills and an adequate exposure to the production environment can understand and operate the system without difficulty.

The software is user friendly and is designed to work fast. The design of the system is such that the user spends very little time on the computer and more time on fabric inspection. Classification and analysis of a single defect will take 10-30 seconds, depending on the type of defect being analyzed, and how quickly the user responds to the queries posed by the system.
2. OPERATIONAL DESCRIPTION

The operation of the system involves two major steps:

1) Establishing the sub-group into which the particular defect under review falls, using the visual characteristics of the defect as a guide.

2) Presenting defect descriptions to the user and assisting in finding the closest match between the actual defect and the defect description.

If the user makes a mistake while providing the set of visual characteristics of a defect, the software allows the user to re-start the analysis from the beginning. Also, if the user has problems in finding an exact match for the defect being inspected from the existing descriptions of a particular defect class, the software allows re-specification of all the input (defect description) data.

2.1 Starting Up FDAS

The current version of FDAS records defect data to an Oracle® database. Along with FDAS software, a database file is also provided. The user must ensure that Oracle is running before starting up FDAS.

To start the system, go to the directory “nxppro\nxpforms\def.” Start the defects analysis software by typing “fdas” at the command prompt. FDAS automatically loads the fabric defects knowledge base.

2.2 Defect Analysis

FDAS depends solely on the user’s input to correctly identify any particular defect in the fabric. The importance of correct input to the system, based on the actual appearance of the defect, cannot, therefore, be over-emphasized. FDAS seeks and receives information in a step-by-step manner and, at each step, it makes certain decisions based on the current information. At any of the input stages, if the user fails to respond to the FDAS query, it will simply remain there and no further progress is possible. If incorrect or inadequate information is provided, FDAS will issue an error message to help the user correct the failure and continue. The cycles of defect identification, analysis and diagnosis are continuous and automatic, until the user decides to quit FDAS.

2.2.1 Input of defect type

As soon as defect analysis is initiated, the system brings up a question (see Figure 2), asking
for the defect type.

Select the best description of the defect type

- Point
- Line
- Area

Figure 2. Defect Type Selection Screen

The three possible answers to this question are:

1. **Point**: For tiny point-sized defects, with area or diameter not exceeding that of a cigarette stub.

2. **Line**: For linear defects of thickness not larger than three or four yarn diameters, and length greater than one centimeter.

3. **Area**: For large random-sized defects extending in both warp and filling directions. This category includes area defects of all possible shapes whose area exceeds that of a cigarette stub.

**2.2.2 Input of defect direction and extent**

After the user indicates the defect type, the software displays further queries as shown in Figure 3 and seeks information on the direction and extent of the defect.

The five possible answers to the direction and extent query are:

1. **Continuously Along Length**: For defects seen running lengthwise (in the warp direction) with an extent of at least 5-6 yards. The length of the defect is, of course, not subject to any upper limit.

2. **Continuously Along Width**: For defects spanning the entire width of the fabric from selvage to selvage.

3. **Partially Along Length**: For defects running lengthwise (in the warp direction) and con-
fined in extent to less than 5-6 yards. The defect terminates after running for a short distance along the length of the fabric.

4. **Partially Along Width**: For defects lying in a widthwise direction (along filling), but not across the entire width.

5. **No Preferred Orientation**: For defects whose orientation is not along either of the two principal fabric directions. Some examples of defects exhibiting random orientation are splotches and stains.

| Direction (orientation) of defect in the fabric: | Continuously Along Length  
|                                               | Partially Along Length  
|                                               | Continuously Along Width  
|                                               | Partially Along Width  
|                                               | No Preferred Orientation  

| Pattern of repeat along the length of the fabric: | Isolated  
|                                                 | Random  
|                                                 | Regularly Repeating  
|                                                 | Continuous  

| Pattern of repeat along the width of the fabric: | Isolated  
|                                                 | Random  
|                                                 | Regularly Repeating  
|                                                 | Continuous  

Figure 3. Screen for Indicating Defect Direction and Pattern of Lengthwise, Widthwise Repetition

2.2.3 **Input of lengthwise repeat pattern**

In the next step, the System retains the screen (displayed above in Figure 3) and expects the user to define the repeat mode in the lengthwise direction.
The possible choices for lengthwise repetition are:

1. **Continuous**: The defect extends continuously along the lengthwise direction (i.e., warp) of the fabric. It must be noted that if “Continuously Along Length” has already been chosen as the directional characteristic, then only this choice is appropriate for the repeat pattern.

2. **Isolated**: The defect occurs just once in the lengthwise direction and then does not recur for a considerable length.

3. **Random**: The defect shows a randomly recurring nature, along the lengthwise direction (i.e., the defect occurs a few times along the warp with no regular repeat pattern).

4. **Regularly Repeating**: The defect repeats at regular intervals along the length. It is not continuous because it is regularly broken-up in the lengthwise direction. It is not random because there is a definite repeat pattern.

2.2.4 **Input of widthwise repeat pattern**

After receiving input on the lengthwise repeat pattern, the System keeps the display screen shown in Figure 3 and expects the user to specify the repeat mode in the widthwise direction. The four choices possible here are similar to those listed for lengthwise direction.

1. **Continuous**: If the defect extends continuously along the filling from selvage to selvage. Note that if “Continuously Along Width” has already been chosen as the directional characteristic, only this choice is appropriate for the widthwise pattern of repeat.

2. **Isolated**: The defect occurs just once in the widthwise direction and then disappears.

3. **Random**: The defect shows a randomly recurring nature across the width (i.e., the defect occurs a few times across the width with no regular repeating pattern).

4. **Regularly Repeating**: The defect repeats at regular intervals across the width. It is not “Continuous” because the occurrence is broken up at regular intervals. It is not “Random” because there is a definite repeating pattern.

2.2.5 **Identification of Defect**

The software now identifies the group of defects pinpointed by the visual characteristics of the defect supplied by the user. There may be any number of different individual defects sharing these common visual characteristics. The software identifies all these possible defects which share the particular visual description.

The system’s next task is to narrow down the different choices in this category, with the help of the user. If the defect category contains less than eight defects, the user is then presented with a precise description of each individual defect, starting with the first defect in the group. Identification is complete when the user matches the defect with one of the defect descriptions.
If the visual description supplied by the user is shared by more than eight defects, a further subclassification of defects falling under the group is necessary. Such a subclassification reduces the diagnosis time by minimizing the number of defect descriptions presented to the user to choose from. Typical choices of subclassification for one of the crowded groups are shown in Figure 4.

![Figure 4. Typical subclassifications for a Line Defect category](image)

Which of the following categories describes the defect the best?

- Shade Variation
- Thick/Prominent Line
- Gap / Depression

For example, in Figure 4 each of the features is used to divide the large parent classification into smaller categories. Each of these smaller sets of defects will share the particular common feature indicated by the user.

Once the set of relevant defects is of manageable size, the process of presenting individual defect descriptions for the user to choose from is the same as before. After the defect is precisely identified, the system displays the probable causes of the particular defect. A list of suggested remedies is also presented.

### 2.3 Diagnosis Capability of the System

The system contains general information on the causes and remedial measures for individual defects in woven fabrics. The System also contains information pertaining to manufacturing technologies such as Open-end Spinning and Air-jet Weaving. Also, the present version of the software includes knowledge for the analysis of fabric defects arising from the indigo-dyeing process.

FDAS, however, is not equipped with knowledge for the analysis of special defects that are characteristic of different brand-name products, process variations, modifications to the production machinery, etc., which may be specific to manufacturing plants or organizations.

The diagnosis information for the whole range of defects is available in the "causes" subdirectory on the computer. The same files are used by the software for providing a detailed causes and remedies analysis, once a particular defect has been identified. These diagnosis files may be
accessed and modified to suit the needs of individual process conditions and manufacturing technologies. FDAS can thus be customized to meet special demands and needs of an organization.
3. SAMPLE SESSIONS

In this section, three typical denim fabric (3/1 twill weave) defects are described, one of each defect type: Point, Line, and Area. Typical interactive screens presented to the user during each defect identification and diagnosis session are also shown.

3.1 Point Defect

For illustration purposes, we have chosen a very simple example of a point defect. Let us assume that the inspector observes a small hole in the fabric, about 1/4" in diameter, with brown edges. This occurs only at one place on the fabric, and then does not appear again.

When the inspector begins the session, the screen shown in Figure 5 is displayed. The inspector selects the type of defect from this screen, by moving up or down between the three choices using the up- and down-arrow keys. To indicate a choice, the inspector moves to the appropriate defect type and presses the <Enter> key.

![Select the best description of the defect type](image)

Figure 5. Defect Type Selection Screen

At this point, the second screen (Figure 6) is displayed to enable the inspector to make selections for the defect’s visual characteristics: direction, lengthwise pattern and widthwise pattern. The up- and down-arrow keys can be used to cycle up and down through the alternatives for the Direction of the defect, until one of these is chosen by the user.

In the current case, the inspector sees a small hole in the fabric, which has no preferred orientation as far as the fabric’s length and width are concerned. Hence the most appropriate choice would be “No Preferred Orientation”. The user goes to this choice with the help of the arrow keys,
and presses <Enter>. The choice made for the Directional characteristic of the defect remains highlighted in a different color. At this point the screen will look as shown below:

![Screen for the Selection of Defect Direction](image)

Figure 6. Screen for the Selection of Defect Direction

The inspector can now proceed to the choices for the Pattern of Repeat in the Lengthwise Direction. The arrow keys can be used to move up and down through the four items on this list: 'Isolated', 'Random', 'Regularly Repeating' and 'Continuous'. The inspector makes a choice by pressing <Enter> on the most suitable repeat pattern ('Isolated' in the present case). 'Isolated' remains highlighted as shown in Figure 7.
| Direction (orientation) of defect in the fabric: | Continuously Along Length  
| | Partially Along Length  
| | Continuously Along Width  
| | Partially Along Width  
| | No Preferred Orientation  

| Pattern of repeat along the length of the fabric: | Random  
| | Regularly Repeating  
| | Continuous  

| Pattern of repeat along the width of the fabric: | Isolated  
| | Random  
| | Regularly Repeating  
| | Continuous  

Figure 7. Screen for the Selection of Lengthwise Pattern

The next visual characteristic to be indicated is the Pattern of Repeat in the Widthwise Direction. Again, the 'Isolated' option appears most suitable in the current case, since there is only one small hole and no repeating pattern across the fabric. Upon selecting 'Isolated' and pressing <Enter>, the screen appears briefly as shown in Figure 8, before disappearing. This indicates successful completion of the task of supplying the defect’s visual characteristics to the System.
The software now identifies the defects class characterized by the visual indications provided by the inspector. In the next step, the system identifies the individual defects which are members of this class of defects and presents the inspector with each defect description, one at a time. The inspector must now see if one of these defect descriptions matches the fabric defect being inspected. In the current case, the first defect description that is presented to the user is shown in Figure 9.

Are there too many knots in the selvage?

True
False
NotKnown
As before, the arrow keys are used to select one of these options. In this case, selvage knots are not the problem being observed in the fabric, so ‘False’ is chosen, and the inspector presses <Enter>. The choice appears highlighted in the selection box on screen, and another <Enter> confirms this choice to the System. The screen disappears. Another selection box bearing the next defect description appears as shown in Figure 10.

![Figure 10. Second Defect Description out of this Point Defect Category](image)

This defect description, too, does not match what the inspector sees in the fabric -- a hole but without broken yarns around the hole. The inspector uses the arrow keys to go to the ‘False’ option, and confirms the selection by pressing <Enter> twice. The next description reads as shown in Figure 11:

![Figure 11. Third Defect Description out of Point Defect Category](image)

The answer is, again, ‘False’. When this screen disappears, the next defect description is exactly the same as the appearance of the defect on the fabric (Figure 12):
Does the defect appear as small holes with burnt edges?

- True
- False
- NotKnown

Figure 12. Fourth (and Precisely Matching) Defect Description from Point Defect Category

In this case, ‘True’ is chosen. As soon as the inspector indicates that the System’s defect description matches the actual fabric defect, FDAS identifies the defect as Burnt Holes. The plausible causes and remedies identified by the system are shown in Figure 13.

The defect is confirmed as Burnt Holes.

Probable Causes

Workers smoking near the loom.

Suggested Remedies

Strictly prohibit smoking near the loom.

F1: Next Session

F2: Exit FDAS

Figure 13. Defect Diagnosis Display

The F1 key clears the diagnosis screen, and re-starts the diagnosis session. The inspector can thus identify and diagnose any number of defects, one after another. The F2 key allows the fabric inspector to exit FDAS, after a consultation session.
3.2 Line Defect

For our second example, let us assume that the inspector observes a single thick and raised line running along the length of the fabric. This is observed at only one place across the width of the cloth.

As before, the inspector begins the session by selecting the type of defect from the first screen. To indicate a choice, the inspector moves to 'Line', which is the appropriate defect type. The first panel looks as in Figure 14.

![Figure 14. Defect Type Selection Screen](image)

The second screen displays all the choices for the defect's visual characteristics such as direction, lengthwise pattern and widthwise pattern. The inspector makes a selection first for the direction or orientation of the defect, using the up- and down-arrow keys to cycle up and down through the alternatives. Since the inspector sees a single long line running down the length of the fabric, the best choice would be 'Continuously Along Length'. The inspector goes to this choice, and presses<Enter>. This choice remains highlighted as shown in Figure 15.
The inspector selects 'Continuous' from among the choices for the Pattern of Repeat in the Lengthwise Direction (Figure 16). This is the only appropriate alternative, since the defect direction has already been specified as extending along the length of the fabric. Once this choice is made by pressing <Enter>, it remains highlighted.
Direction (orientation) of defect in the fabric:

- Continuously Along Length
- Partially Along Length
- Continuously Along Width
- Partially Along Width
- No Preferred Orientation

Pattern of repeat along the length of the fabric:

- Isolated
- Random
- Regularly Repeating

Pattern of repeat along the width of the fabric:

- Isolated
- Random
- Regularly Repeating
- Continuous

Figure 16. Screen for the Selection of Lengthwise Pattern

Finally, the inspector must make a choice for the Pattern of Repeat in the Widthwise Direction. The 'Isolated' option appears most suitable in the current case, since there is only a single defective line running lengthwise, with no more occurrences or repeating pattern across the fabric. Upon selecting 'Isolated' with the arrow keys and pressing <Enter>, the screen will briefly appear as shown in Figure 17.
<table>
<thead>
<tr>
<th>Direction (orientation) of defect in the fabric:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partially Along Length</td>
</tr>
<tr>
<td>Continuously Along Width</td>
</tr>
<tr>
<td>Partially Along Width</td>
</tr>
<tr>
<td>No Preferred Orientation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pattern of repeat along the length of the fabric:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated</td>
</tr>
<tr>
<td>Random</td>
</tr>
<tr>
<td>Regularly Repeating</td>
</tr>
<tr>
<td>Continuous</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pattern of repeat along the width of the fabric:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated</td>
</tr>
<tr>
<td>Random</td>
</tr>
<tr>
<td>Regularly Repeating</td>
</tr>
<tr>
<td>Continuous</td>
</tr>
</tbody>
</table>

Figure 17. Screen for the Selection of Widthwise Pattern

The system now has a complete set of visual characteristics of this defect. This set denotes a group or category of defects, with every defect in this group sharing this general set of classification parameters.

In the present case, a large number of defects share the visual characteristics that mark this category. Consequently, the system presents the inspector with a further choice from among four sub-categories of defects (as shown in Figure 18) instead of starting to go through a set of individual defect descriptions.
Which of the following categories describes the defect the best?

- Shade Variation
- Thick/Prominent Line

Figure 18. Defect Sub-Categories for Line Defect Category

For the current defect, the appropriate category would be Thick/Prominent Line. Now, the computer will pinpoint all the defects which belong to the category ‘Thick/Prominent Line’, and the inspector will be presented with only these defect descriptions.

Now FDAS begins with the first defect description, by displaying the screen shown in Figure 19.

Does the defect appear to be a yarn thicker than normal?

- True
- False
- NotKnown

Figure 19. First Defect Description of Thick/Prominent Line Sub-Category

Let us say the inspector examines the fabric and finds that, while this defect description is fairly close, the yarns at the site of the defect are quite normal in diameter. Thus the problem is really something else, and the inspector chooses to select the ‘False’ option with the arrow keys, followed by <Enter>. This enters the user’s choice in the selection box. A second <Enter> confirms this choice to FDAS. FDAS then discards that defect as a valid choice, and displays the next defect description, shown in Figure 20.
Does the defect appear as cords or lines of higher ends density in the selvage?

- True
- False
- NotKnown

Figure 20. Second Defect Description from Thick/Prominent Line Sub-Category

On inspecting the fabric, the inspector does not find any increase in density of warp yarns around the area of the defect. So, 'False' is chosen. The system proceeds to put up the next defect description for the user's review (Figure 21).

Does the defect appear as a thick streak along the fabric length, with two ends weaving in the same pattern instead of one?

- True
- False
- NotKnown

Figure 21. Third Defect Description from Thick/Prominent Line Sub-Category

The inspector finds that this defect description does indeed match what is seen on the fabric. The fabric defect does have two neighboring warp yarns weaving together, which is a defect since it is a twill weave fabric. The user selects 'True'. FDAS identifies this defect as a Double End. Finally it displays an analysis of the causes of the defect, and suggests remedies (Figure 22).
The defect is confirmed as a Double End.

**Probable Causes**

Wrong drawing-in order, or a broken end continuing to weave with an adjacent end.

**Suggested Remedies**

Drawing-in has to be done with utmost care and after gaiting a new beam, the technicians must inspect the fabric carefully for any defects.

If the yarn is too hairy, increased size add-on may be necessary.

Using heavier dropwires will ensure the stoppage of loom in case of end-breaks.

---

**Figure 22. Diagnosis Screen for the Double End Defect**

### 3.3 Area Defect

Assume that the inspector observes a small area in the fabric where the lengthwise (warp) threads appear stretched and a number of knots are present in the warp threads. Also assume this defect is observed only once in the entire piece of fabric being inspected.

The choices made by the inspector to correctly describe this defect are shown highlighted in Figures 23 and 24. The method of making selections from a menu presented to the inspector has been described in the previous two examples.
Select the best description of the defect type

Point
Line

Figure 23. Defect Type Selection Screen

Direction (orientation) of defect in the fabric:

Pattern of repeat along the length of the fabric:

Pattern of repeat along the width of the fabric:

Continuous Along Length
Partially Along Length
Continuously Along Width
Partially Along Width
No Preferred Orientation

Random
Regularly Repeating
Continuous

Random
Regularly Repeating
Continuous

Figure 24. Screen for the Selection of Defect Direction

The system now identifies the defect category based on all these visual indications. Since more than eight defects belong to this category, they are further classified based on their nature. For this, the system presents the screen shown in Figure 25.
Which of the following categories describes the defect the best?

- Holes/Torn fabric
- **Knots/Stretched Warp Yarns**
- Stains/Shade Variation
- X

Figure 25. Defect Sub-Categories for this Area Defect Category

The observed defect falls best into the sub-category “Knots/Stretched Warp Yarns”. Upon selection of “Knots/Stretched Yarns”, the system starts presenting the exact descriptions of individual defects as before. In this case, the first description presented to the inspector describes the defect correctly:

Is the defective area characterized by stretched warp threads, and knots in a small area?

- **True**
- False
- NotKnown

Figure 26. First Defect Description for this Knots/Stretched Warp Yarns Sub-Category

When the inspector confirms the description in Figure 26 as matching the defect observed on the fabric by pressing <Enter>, FDAS displays the window in Figure 27 showing the identity of the defect, its probable causes and suggested remedies.
The defect is confirmed as Break Out.

**Probable Causes**

Excessive yarn hairiness or tangling of warp yarns due to wild yarn, bad knots, etc.

**Suggested Remedies**

In case of hairy yarn, increased size take-up is required.

Where over-head cleaning is used in the weaving room, the tie threads for repairing warp breaks should be carried by the operator rather than being placed on the loom.

More frequent cleaning and better house keeping in preparatory processes will help to avoid the problem of wild yarn.

Ensure the usage of weaver’s or fisherman’s knot with the tail length less than 1/2 inch.

![F1: Next Session](image)

![F2: Exit FDAS](image)

Figure 27. Diagnosis Screen for a Break Out Defect.

By using the down arrow key, the user can scroll down the displayed screen one line at a time or can go to the next page of the file by pressing <PgDn>. The <PgDn> option will show extensions of the diagnosis file, if any.
4. ERROR HANDLING BY FDAS

The user can possibly commit two kinds of errors in describing a defect to FDAS: the visual characteristics of the defect (type, direction, etc.) may not be correctly described (Failure Type 1) or there may be an error in matching the appearance of the defect with the choices provided by FDAS (Failure Type 2). In both instances, FDAS cannot reach a conclusion and will display an error message prompting the user to redescribe the defect. The behavior of the System under these two circumstances is described in this section.

4.1 Failure Type 1

Let's use the example in Section 3.2, where all the steps involved in the diagnosis of a Double End have been described. Assume that the user makes right choices in describing the defect type, direction (orientation), and widthwise pattern but indicates the lengthwise pattern as “Isolated”. This is incorrect as the user has already described the direction as “Continuously Along Length”. FDAS points out this error to the user in the window shown in Figure 28. The user is shown all the input for verification. The user can start another session and re-describe the defect.

The pattern of the defect described does not match that of any defect in FDAS.

The described pattern is presented below for verification:

<table>
<thead>
<tr>
<th>Fabric defect type</th>
<th>Line defect direction</th>
<th>Line defect lengthwise pattern</th>
<th>Line defect widthwise pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>Continuously along length</td>
<td>Isolated</td>
<td>Isolated</td>
</tr>
</tbody>
</table>

[F1: Next Session]

[F2: Exit FDAS]

Figure 28. Failure by User to Correctly Describe Defect’s Visual Characteristics
4.2 Failure Type 2

In the illustration of Section 3.2, the user rejects the first two defect descriptions presented by the system and accepts the third for the successful completion of the diagnosis.

Now, let us assume that the user does not carefully match the description presented by the system with the actual defect. The user may reject all the descriptions presented. This could also happen if the system has no knowledge about the defect currently observed. In the former case, the defect can be successfully diagnosed by restarting another session and describing the defect carefully. The window shown in Figure 29 is presented to the user to indicate the diagnosis failure.

All the defect descriptions within your chosen defect category have been shown to you. However, you have not selected any.

Please re-start the system. Then you may choose to either

1. Re-select the same defect category (give the same visual defect description: type, direction, etc.) as before and go through the choices again.

2. Examine the actual defect carefully. It is possible that another defect category (different defect descriptions) is more correct and its individual defects may be more close to the one being actually observed in the fabric.

\[ \text{F1: Next Session} \]
\[ \text{F2: Exit FDAS} \]

Figure 29. Diagnosis Failure; User Does Not Correctly Match Any Defect Description

***
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING: DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK


Research sponsored by

Defense Logistics Agency
DLA-PRM
Cameron Station
Alexandria, Virginia

DLA Contract #: DLA-900-87-D-0018-0003

Reported by:

Dr. Sundaresan Jayaraman
Principal Investigator

Georgia Institute of Technology
School of Textile & Fiber Engineering
Atlanta, GA 30332-0295

Tel: 404-894-2490
Fax: 404-894-8780

Georgia Tech Project #: E-27-637

November 1988 - November 1991

SJ-TR-DEFE-9202
Research has been carried out to analyze defects in apparel manufacturing. Two knowledge-based software systems -- FDAS (Fabric Defects Analysis System) and SDAS (Sewing Defects Analysis System) -- have been developed. The research has been funded by the U.S. Defense Logistics Agency under contract number DLA-900-87-D-0018-0003.

FDAS covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. SDAS covers the defects occurring in the cutting, sewing, finishing and packing departments of an apparel plant producing denim trousers. Based on the visual description of the defect in the fabric (type, orientation and mode of repetition of the defect), FDAS identifies the defect and suggests possible causes and remedies.
ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING:
DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK


Research sponsored by

Defense Logistics Agency
DLA-PRM
Cameron Station
Alexandria, Virginia

DLA Contract #: DLA-900-87-D-0018-0003

Reported by:

Dr. Sundaresan Jayaraman
Principal Investigator

Georgia Institute of Technology
School of Textile & Fiber Engineering
Atlanta, GA 30332-0295

Tel: 404-894-2490
Fax: 404-894-8780

Georgia Tech Project #: E-27-637

November 1988 - November 1991

SJ-TR-DEFE-9202
Research Project Personnel

K. Srinivasan
Graduate Research Assistant

Dr. Krishna Parachuru
Dr. Phiroze H. Dastoor
Research Investigators

Dr. Sundaresan Jayaraman
Principal Investigator
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>iv</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 What is SDAS?</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Working Principle of SDAS</td>
<td>1</td>
</tr>
<tr>
<td>1.3 Scope and Applications of SDAS</td>
<td>1</td>
</tr>
<tr>
<td>1.4 Requirements From the User</td>
<td>3</td>
</tr>
<tr>
<td>2. OPERATIONAL DESCRIPTION</td>
<td>4</td>
</tr>
<tr>
<td>2.1 Starting Up SDAS</td>
<td>4</td>
</tr>
<tr>
<td>2.2 Defect Analysis</td>
<td>4</td>
</tr>
<tr>
<td>2.2.1 Input of defect location</td>
<td>5</td>
</tr>
<tr>
<td>2.2.2 Input of defect type</td>
<td>6</td>
</tr>
<tr>
<td>2.2.3 Diagnostics from SDAS</td>
<td>7</td>
</tr>
<tr>
<td>2.2.4 MIL-87062 Specifications</td>
<td>8</td>
</tr>
<tr>
<td>2.3 Diagnosis Capability of the System</td>
<td>10</td>
</tr>
<tr>
<td>3. SAMPLE SESSION</td>
<td>11</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Research has been carried out to analyze defects in apparel manufacturing. Two knowledge-based software systems -- FDAS (Fabric Defects Analysis System) and SDAS (Sewing Defects Analysis System) -- have been developed. The research has been funded by the U.S. Defense Logistics Agency under contract number DLA-900-87-D-0018-0003.

FDAS covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. SDAS covers the defects occurring in the cutting, sewing, finishing and packing departments of an apparel plant producing denim trousers. Based on the visual description of the defect in the fabric (type, orientation and mode of repetition of the defect), FDAS identifies the defect and suggests possible causes and remedies.

SDAS uses information on the location and nature of the defect to identify the manufacturing operation causing the defect and displays possible causes and remedies for the defect. SDAS also has a provision to display the relevant construction specifications (MIL-SPEC) for the assembly operation causing the defect. Both FDAS and SDAS are implemented in Nexpert Object and are linked to a relational database using Oracle. They run under both MS-DOS and Unix environments. Software manuals for using FDAS and SDAS have been produced.

FDAS is intended for use at the greige or finished fabric inspection station in a weaving plant. It can also serve as a backend to a vision-based inspection system. SDAS can be used by an apparel plant for the inspection of trousers.

About the Report: The final technical report is presented in three volumes. In Volume I, the details of the research effort are discussed along with recommendations for additional research. Volume II is the software user manual for FDAS, while Volume III (the present volume) is the software user manual for SDAS.
1. INTRODUCTION

1.1 What is SDAS?

SDAS (Sewing Defects Analysis System) is an identification and diagnosis system for defects encountered in the manufacturing of military utility trousers as described in MIL-STD-87062. The system covers the common defects occurring during garment manufacturing operations such as cutting, sewing and finishing. The development of the system has been funded by the U.S. Defense Logistics Agency.

1.2 Working Principle of SDAS

The flowchart in Figure 1 summarizes the working of SDAS.

First, the user indicates the defect location (waistband, pocket, etc.) and the defect type (open seam, broken thread, etc.). After receiving this information, SDAS attempts to find what manufacturing process could have caused the defect. If the existing information is not sufficient to do this, it seeks more specific information regarding the location of the defect (right end of the waistband, pocket edge, etc.) and the nature of the defect (badly formed or badly placed belt-loops, etc.). Once SDAS is able to find the manufacturing operation causing the defect, it displays possible causes and suggested remedies to the user. The system also records the information regarding the defect location, type and manufacturing operation causing the defect in a database. Along with this diagnosis process, the system compiles a list of all the utility trouser construction specifications (MIL-87062) relevant to the defect described by the user and displays it if the user so desires.

1.3 Scope and Applications of SDAS

SDAS is tailored for analysis of defects occurring in military utility trousers. Its working principle can be used for building similar systems for other types of garments as well. However, this will require additional effort in knowledge acquisition, testing, etc., as the manufacturing process sequences differ widely for different garment types.

Classification and analysis of defect occurrences on a day-to-day basis will be helpful in maximizing the percentage of first quality production. The link to a database enables SDAS to be used for the analysis and control of defects. It is particularly useful to keep track of defect occurrences over short and long-term intervals and to initiate remedial action when required. Database software will also simplify report generation and quality monitoring.
Obtain information on the location and the type of the defect, from user

Obtain more specific information on the nature and the location of the defect

Is it possible to pin-point the operation causing the defect?

Yes

Display the information regarding the process which might be causing the defect and appropriate remedies

No

Does the user want to see relevant specifications?

Yes

Display relevant utility trouser construction specifications (MIL-STD-87062)

No

Process next defect

Figure 1. Flowchart for the Analysis of a Single Defect
1.4 Requirements From the User

To make efficient use of SDAS, the user should possess a basic understanding of the system. It is very important to remember that the SDAS is an aid for the classification and analysis of garment defects and not a replacement for a sharp-eyed and experienced inspector.

The learning time depends on the background and education level of the user but is not expected to be more than a day or two at most. An average high school graduate with basic analytical skills and an adequate exposure to the production environment can understand and operate the system.

The software is user-friendly and is designed to work fast. The design of the system is such that the user spends very little time on the computer and more time on garment inspection. Classification and analysis of a single defect will take 10-20 seconds, depending on the type of defect being analyzed, and how quickly the user responds to the queries posed by the system.
2. OPERATIONAL DESCRIPTION

The operation of the system involves three major steps:

1) Obtaining information about the defect from the user.

2) Establishing the specific manufacturing process responsible for the particular defect under review and simultaneously compiling the list of relevant MIL-STD-87062 specifications, based on information provided by the user.

3) Presenting the probable causes and suggested remedies (and also the specifications list, if desired) to the user, and writing the information to a database.

If the user makes a mistake while providing the set of visual characteristics of a defect, the software allows the user to re-start the analysis from the beginning. In fact, at any point during a session, the user is free to abort it and start a fresh one using the F1 key.

2.1 Starting Up SDAS

The current version of SDAS records defect data to an Oracle® database. Along with SDAS software, a database file is also provided. Ensure that Oracle is running before starting up SDAS.

Go to the directory “\expert\sewdef.” Start the defects analysis software by typing “sdas” at the command prompt. SDAS automatically loads the sewing defects knowledge base.

2.2 Defect Analysis

The system depends solely on the user’s input to correctly identify any particular defect in a garment. The importance of correct input to the system, based on the actual appearance of the defect, therefore, cannot be over-emphasized. SDAS seeks and receives information in a step-by-step manner and, at each step, it makes certain decisions based on the current information. At any of the input stages, if the user fails to respond to SDAS’s query, no further progress is possible. However, the user can choose to abort the current analysis and start all over again by using the F1 key. The cycles of defect analysis and diagnosis are continuous and automatic, until the user decides to quit SDAS (using the F2 key).
2.2.1 Input of defect location

As soon as defect analysis is initiated, the system brings up a question (see Figure 2), asking for the defect location.

Figure 2. Defect Location Selection Screen

Let us assume the user selects Seat Seam as the location where the defect is observed.
2.2.2 Input of defect type

After the user indicates the defect location, the software displays a query as shown in Figure 3 and seeks information on the defect type.

What is the nature of the defect?

- Broken_Thread
- Exposed_Notches
- Insecure_Backstitch
- Irregular_Stitch_Gauge
- Loose/Tight_Thread
- Mislocated_Reinforcement
- Needle_Cheat
- Open_Seam
- Pleated_Seam
- Puckered_Seam
- Raw_Edge
- Run_Off
- Skipped_Stitch
- Twisted_Seam
- Uneven_Stitch_Line

Figure 3. Screen for the Indication of Defect Type

Let us assume the user selects Misaligned Seam as the type of the observed defect.
2.2.3 Diagnostics from SDAS

In this case, the system needs no further information to establish the manufacturing process causing the defect. It displays a screen containing information about the probable causes and remedies for the defect described by the user (Figure 4). This information is also written to a database.
Checkpoints for Misaligned Seam:

1. A bent needle can cause the stitch line to deviate during stitching, and result in a misaligned seam or even a run-off.

2. On a completely manual machine, this defect can be the result of the operator lining up the feed into the sewing head in a wrong position from the very start.

3. If a folder is being used, it must be of a suitable type and must be set correctly to give the required seam margins relative to the sewing head. The operator must not hold back on the fabric plies as they are run through the folder.

4. Too high a setting for the feed dog will cause backfeed of the lower ply as the feed dog performs its return traverse. This will result in a skewing of the two fabric plies going into the seam, and variation in seam margin.

5. The same differential feed problem will be observed if the pressure exerted by the presser foot is too high; in this case, it will be the top ply being held back from its usual feed rate.

Specific Checkpoints for Misaligned Seams at the Join Seat Seam Operation:

1. Operator error is likely to be the main cause for a Misaligned seat seam, in lining up the edges of the two plies perfectly for feed into the folder, and maintaining this same alignment during the stitch run.

2. If the operator has a practice of overfeeding material into the folder, the extra fabric is absorbed into the margin rather than into the felled seam.

Figure 4. Diagnostics from SDAS

2.2.4 MIL 87062 Specifications

SDAS first asks the user if the specifications are to be displayed (Figure 5). If the user de-
sires to see the specifications, they are displayed as shown in Figure 6.

Do you wish to see the relevant garment construction (MIL-87062) specifications?

| True  | False | NotKnown |

Figure 5. Option for User to see MIL-87062 Specifications

Specification #1

Description:
Join seat seam with a double stitched seam with right back lapped over left back. The seat seam and crotch seam shall not be out of alignment by more than 3/8 inch.

Allowed Tolerance:
Unknown

Seam Type:
Lapped, Lsd-2

Stitch Type:
301, 401

Stitches/Inch (recommended):
8-10

F1 Next Session

F2 Exit FDAS

Figure 6. Relevant Garment Construction Specifications (MIL-87062)
2.3 Diagnosis Capability of the System

The diagnosis information for the defects is available in the “causes” subdirectory on the computer. These files are highly modular, i.e., information in these files is very specific to defects of particular types, and at particular locations. As SDAS obtains information from the user, it compiles information from these files according to the information provided. This dynamic compilation of the diagnostics files to be displayed to the user ensures that all information relevant to the defect described by the user is displayed. For example, Figure 4 contains information in general about Misaligned Seam (defect type specified by the user) and also information specific to Seat Seam (defect location specified by the user).

These diagnosis files may be accessed and modified to suit the needs of individual process conditions and manufacturing technologies. The changes to the diagnosis files can be made with the help of a text editor. SDAS can thus be customized to meet special demands and needs.

The other output from the system, the construction specifications (MIL-87062), is also very specific to the defect described by the user.
3. SAMPLE SESSION

The previous section explained the working of SDAS, using the example of a misaligned seat seam. In this section another example (needle chew on the pocket) is provided. In this case, SDAS will not be able to establish the cause of the defect directly from defect location and type as in the previous case, and hence will seek more specific information from the user.

The user inputs for the defect location and type are shown in Figures 7 and 8. A defect fitting this description could have been caused by one of the several manufacturing operations such as, making of the patch-pocket, positioning it, or hemming it. To identify the culprit process exactly, SDAS goes on to ask more specific questions about the nature of the defect. It will first ask if the defect is due to the way the pocket has been hemmed (Figure 9). Assume the user selects “False” in response to this query. SDAS goes on to ask if the defect is due to bad positioning or stitching (Figure 10). If the user’s answer is in the affirmative, SDAS displays the diagnosis (Figure 11), writes to the database and displays the relevant specifications in case the user wishes to see them (Figure 12).

Where do you see the current defect?

Bartack
Belt_Loops
Buttonhole
Crotch_Seam
Dart
Inseam
Inside_label
Left_Fly
Left_Fly_Jstitch
Outseam
Pocket
Right_Fly_Inside
Right_Fly_Outside
Seat_Seam
Waistband

Figure 7. Defect Location Selection Screen
What is the nature of the defect?

Broken_Thread
Exposed_Notches
Insecure_Backstitch
Irregular_Stitch_Gauge
Loose/Tight_Thread
Misaligned_Seam
Mislocated_Reinforcement
Needle_Cheek
Open_Seam
Pleated_Seam
Puckered_Seam
Raw_Edge
Run_Off
Skipped_Stitch
Twisted_Seam
Uneven_Stitch_Line

Figure 8. Screen for the Indication of Defect Type
Do you see a defect in the way the pocket has been hemmed?

False

True

False

NotKnown

Figure 9. A Specific Question about the Defect Type

Is there a problem with the pocket's positioning or its stitching?

False

True

False

NotKnown

Figure 10. Another Specific Question about the Defect Type
Checkpoints for Needle Chew Defects, in general:

1. The first place to look is a broken or bent needle, or a burr on the needle. A broken needle would cause entry into the same small region of the fabric without any stitching since loop formation does not take place. A rough needle surface traps the fabric and pulls it out of the plane causing irregular feed and repeated stitching in a very small area.

2. The feed dog setting may be too low or too high. If it is set too low, this results in inadequate forward motion of the fabric at each sewing cycle. If it is set too high then there will be excessive backward feed of the material when the feed dog is on its return movement at the end of a stitch.

3. There may not be enough presser foot pressure to keep the fabric flat and feeding evenly despite the lateral forces exerted by the needle.

Checkpoints for Needle Chew Defects, at the Attach Patch Pocket Operation:

1. On an automatic pocket setter, the feed mechanisms must be verified to be working correctly. There should be no snagging of panel and pocket during the attachment operation which could restrict the movement of the pieces and cause the stitching to continue in a local area.

2. If there is a needle chew at one of the corner bartacks, it is almost always a broken needle that is the cause. The very high fabric thickness at these places may have caused the tacking needle to break.

Figure 11. Diagnosis from SDAS
Specification #1

Description:
Position patch pockets to their respective parts according to pattern marks. Fold under raw edges 5/16 to 3/8 inch and double stitch the sides and bottom edges of pockets through all plies.

Allowed Tolerance:
The pocket shape and space between bartacks (operation 14) for all sizes shall not vary more than 1/4 inch from the finished pocket template.

Seam Type:
Lapped, LSd-2

Stitch Type:
301, 401

Stitches/Inch (recommended):
8-10

Figure 12. Relevant Garment Construction Specifications (MIL-87062)