Final Summary Report

"THE SYSTEMS ASPECT OF HARVESTING

AND TRANSPORTATION"

Sponsored Research Project B-1009

(E-24-601)

Conducted By

The School of Industrial and Systems Engineering

Georgia Institute of Technology

Atlanta, Georgia 30332

for

The Southern Executives Association

July 1, 1967

December 31, 1971

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I. NATURE OF THE RESEARCH PROGRAM

Objectives: The objective of the Research shall be the structuring of a systems model or models sufficient to validly represent the endeavors involved in the "Harvesting and Transportation of Pulpwood." Such model or models shall portray the significant characteristics and constraints on such systems as they now exist, and as they are likely to exist prior to the year 2000. Such model or models shall portray the compatibility or incompatibility of the various existing resource ownership patterns, silvicultural aspects, labor patterns, techniques of harvesting, and techniques of transportation; and such patterns and techniques anticipated prior to the year 2000. The resultant model or models shall have the ability of quantifying the productivity of the major resources utilized in the system and its relationship to economic investment and resource pricing.

Scope: The Research shall be limited to the "Southern Pines Producing" geographical region and shall consider the resource material for paper manufacturing from the time of the planting of the seed to the time of chemical treatment of the fiber in the paper-making process. The Research shall consider transportation of the resource material in any fiber form from stump to paper-making facility. For purposes of model construction, one paper-making facility and its resource area shall be the endeavor unit to be measured, providing its interfaces with other adjacent facilities and resource areas are firmly delineated. Non-typical facilities or resource areas shall be given due consideration. Provision in the model or models shall be made to quantify the social and political

interrelationships between the paper-making facility and its resource owners and processors, to equate them to the economic quantification of the model or models. Management techniques and business skills of the resource harvesters shall be given consideration in the model building processes.

Method of Approach: After an introductory and familiarization period necessary for the Research Group to become acquainted with the current state of the art, present characteristics and constraints on the system shall be defined and quantified using the systems approach for analytical purpose. Inputs, outputs, and levels will be explored for model compatibility and classification, and to define problem areas within the models. Various models of the present systems will then be designed for testing the present system, using simulation techniques apparently applicable. After problem areas have been minimized, then the most likely model or combination of models will be selected for testing the parameters for sensitivity. Further testing shall be made to insure the model or combination of models is responsive to the objectives of the research program. Results shall be reported in accordance with the schedule and format proposed by the Research Sponsor.

II. GOALS OF THE FIRST TWO YEARS OF THE PROGRAM

Considering little prior work in the pulpwood harvesting and transportation field had been previously performed in the School of Industrial Engineering, the first two goals of the program were:

(A) Indoctrination, and

(B) Involvement.

Indoctrination was accomplished by a comprehensive visitation program to producers, dealer organizations, wood yards, managed Forests, pulp and paper mills and professional meetings. This was coupled with detailed literature searches as outlined in the bibliographies of the research reports abstracted in this report. Attendance at professional meetings such as T. A. P. P. I., A. P. A., and F. P. R. C. and joint meetings with the A. P. A. Harvesting Research Group, at Dr. Walbridge's suggestion, were most beneficial. Weekly meetings were held with the entire Project group, in the early stages of the program, to promote free exchange of information and resource information encountered. Various S. E. A. mills and forest management groups were extremely helpful during this indoctrination period.

Involvement was accomplished simply by putting people to work doing something in which <u>they</u> were particularly interested. Wide latitude was given all members of the Project group to study, analyze and report on facets of the general problem which, in their initial opinion, would result in new conclusions. Naturally, as this work was performed and more resources information became available, many of the participants found that their original ideas had already been well processed elsewhere, so they were forced to modify their original goals. Practically the only limitation placed on

these early projects was that the approach must be made from the systems viewpoint. This caused some difficulty as much of the resource information appeared to be concerned with one machine, or one crew, or one company. Both qualitative and quantitative works were produced, generally as term papers or term project reports. The quality ranged from excellent to poor as would be expected, but the results of creating active involvement was achieved.

Further goals of the first two years of the program were to develop:

(C) Continuity, and

(D) Definition of scope.

Continuity of effort became more apparent in the second year. As non-funded Graduate and Undergraduate participants produced various works, the necessity for amplification or further study in areas of great potential became apparent. Thus the work performed by funded Graduate Research assistants became a foundation upon which all could build. A study of the abstracts in Section VII demonstrates how this was slowly accomplished. Programs and simulations developed with synthetic data have revealed what sort of "real world" data was necessary. This was gathered from the S.E.A. membership in order that there be a continuation from theoretical to applied results.

Definition of scope for the research effort was an area of major concern at the end of the first year. The variety of works performed by the Project group had, "so to speak", unlocked many more facets of the basic problem than initially were outlined to the original three Research Associates. Using the systems approach to the problem naturally broadened the research effort beyond the one forest, one producer, one woodyard pulpwood producing activities. Proofs of some of the tentative conclusions of early works even within the

reference framework of one mill and its support systems, appeared much more involved than orginally anticipated. This can be revealed in a comment made by J. J. Stark upon submission of his Master Thesis, "Two more pages and this thesis would have made a fine Ph.D. dissertation." The Research Associates therefore had to set reasonable restrictions on the scope of work being performed. This could not be done until the "involvement" stage in the development of the program had been accomplished.

III. GOALS OF THE LATER YEARS OF THE PROGRAM

Four goals were basically been established for the later years the program. The first two of these are:

(A) Refinement, and

(B) Consolidation.

Refinement was necessary in order to place the creative work already performed into easily useable form. With scope fairly well defined, the basic individual work had to be tested and evaluated and then revised to fit within the overall purposes of the Research Program.

Consolidation of various small models, created individually, into one or more master models of the area under study consumed an ever increasing proportion of the time available to the Project group. In the simulation oriented research areas there appeared to be at least seven typical types of models necessary to be responsive to the purpose of the Research. These were:

(a) A Forecasting Model

(b) An Organizational Policy Model

(c) An Equipment Systems Model

(d) A Forest Management Model

(e) A Design Evaluation Model

(f) A Financial Evaluation Model

(g) A Transportation Analysis Model

Individual models of a restricted nature were created for all typical model types. However, one of the concern of the Project Director was to allow Freedom of research outside the scope of systems simulation. Therefore, other research was allowed to continue. Both refinement and consolidation stages of any research program always consume more man-hours than originally contemplated. This was true in the case of the work reported hereafter.

The second pair of goals for the later years were:

(C) Communications, and

(D) Sponsor Comprehension and Acceptance.

Communications can cover a wide variety of methods of presenting research activities, ranging orally from informal presentation of research to a small group to the short course-seminar presentation open to industry attendance, and ranging verbally from the in-house written report for the sponsor group to the submission of refereed research papers to international publications. S. E. A. advised the research group to develop these lines of communications with little restriction attached to dissemination policy.

Sponsor comprehension and acceptance was paramount to a project of this nature. Having placed a research group in position to become involved in a new environment was one thing. Maintaining and amplifying involvement, particularly at the undergraduate and graduate levels was an entirely different problem as the participants constantly changed from one year to the next, sometimes before they could even learn of the sponsor's reaction. So, quite naturally, as work was produced and communicated to the sponsoring group, as reported in the abstracts found in Section VII and VIII, and in other presentations to them, the Project group was anxious for the sponsor feedback for this could have stimulated greater responsive effort. The Research group anticipated acceptance, but, as in all research programs, rejection of segments of the research or requests for modifications did occur. The Project group, therefore, in consultation with S. E. A. counsel gracefully modified those portions of its efforts to best fit the needs of the Sponsoring group.

IV. FACULTY INVOLVEMENT

Two members of the Georgia Tech faculty, Dr. Joseph Krol, and Mr. N. K. Rogers, and one member of the University of Georgia faculty, Dr. Peter Dyson, were funded in the S. E. A. sponsored work. Approximately, fifteen other members of the Georgia Tech faculty contributed to the project in the direction or reviewing functions required.

Dr. Krol directed the work which resulted in five of the Special Research Reports, while Mr. Rogers directed the work in the remaining six Special Research areas, all previously submitted to the sponsoring agency. Dr. Dyson acted as advisor for silvacultural and other forestry consideration and was directly involved in six of the eleven problem areas. Mr. Rogers acted as Project Director.

All three faculty members have given lecturer, seminars, and presented papers as a result of the research project. All three faculty members have published and disseminated the general results of the research to industry. Considerable interest in research activities in the pulpwood industry was brought about by these activities.

V. GRADUATE STUDENT INVOLVEMENT

Approximately, nine Graduate students were funded by the project for six to fifteen months each. Approximately twelve other graduate students performed Special Research Projects or Masters Thesis in this work area during its funded life.

In fact the major work in six of the eleven Special Research Reports furnished to the sponsor were performed by non-funded Graduate students who developed an interest in this work area. Further interest at the Graduate level was stimulated by course work given to the general Graduate students based on the problems encountered in the research area.

Unhappily, to our knowledge after four years of research effort, not one of the Graduate students exposed to the challenges of the research area have been employed by pulp or paper industries. In only four instances were the twenty-odd Graduate students directly involved offered positions in the industry and in those instances the salary offered was not competitive with other industrial opportunities.

VI. UNDERGRADUATE STUDENT INVOLVEMENT

Approximately four Undergraduate students received funded benefits from the research program. In several instances the completeness of the documentation of computer programs presented in the Special Research Reports were the result of a number of months of effort on their behalf.

Some further student interest of the undergraduate level was generated by their being made aware of the large member of faculty and graduate students at the School of Industrial and Systems Engineering who were participating to some degree in the project.

Undergraduate students attended Georgia Tech and industry sponsored seminars and meetings relating to the work area.

VII. SIMULATION ORIENTED RESEARCH

As the main thrust of the research was to apply systems analysis techniques to the problems involved in the harvesting and transportation of pulpwood, the creation of many different models was attempted. Each was created for use by the individual mill or company in the solution of its own particular problems. The scope of application to the single product pulpwood industry was much wider than had originally been anticipated and eight computer programs were developed for systems analysis activities. The basic uses are discussed below.

1. Scope of Computer Simulation Uses In The Pulpwood Industry

It is therefore approaprite to simmarize the variety of uses found for computer simulation programs.

a. To gain an appreciation for the future production required in the field under study, it was felt appropriate to design a long-range forecasting model for the industry. This required a dynamic feedback model using continuous simulation. It was used primarily to analyze the prediction function in the pulpwood paper industry. This particular simulation model was expected to be of interest to the sales departments of the various paper companies and their dealer/producer systems in order to predict the volume of work to be performed in the future and the revenues to be obtained therefrom. It required a long-range model analyzing the order-production flow relationship.

b. It then became necessary to examine the types of organizations that are used to produce the product. To accomplish this objective, a model was needed wherein one could experiment with changes of organizational policies within these systems. This required another use of continuous computer simulation techniques to create a dynamic feedback model which could analyze the communication functions in the system and their response times. This

model would be of particular interest to the procurement/dealer system in any paper company, particular as the output of such computer model predicates not only the inventories of goods on hand and the time lags between orders and resultant production, but to a greater degree the organizational reaction time of the system which predicates its costs. A short-term time span was used and, for short range analysis of the order-production flow relationships, this model was found to be an especially helpful tool in studying anticipated delays and in finding the difficulties in communication flows within existing organizations.

c. At this point, it became desirable to examine the changes which might occur in the production potential of the physical system involved in the harvesting function. Hence, a computer simulation model was built to experiment with changes in or substitution of, different physical components in the system. In this instance the producer is moving wood through a machine system. Thus, a discrete model was necessary, for the user was primarily interested in determining the utilization rates and queues within the production function being analyzed. This simulation model, it was felt, would be of particular interest to the producer himself, as his selection of the many physical harvesting alternatives predicates his costs. This was a short-range model primarily concerned with analyzing physical alternatives.

d. The question then arose regarding some method of predicting the forest to be worked on in the future and experimenting with changes in resource allocation policies within the system. This work was undertaken and required the combination of a continuous and a discrete simulation model. The discrete section of the model was used to analyze various allocation decisions, and these results were pumped into the continuous section of the program to

determine investment outcomes. It was felt that this type of analysis would be particularly useful to the land use or forestry group within a paper company primarily involved with investment decisions. Naturally, this was a long-range model, but again primarily concerned with physical alternatives and their resultant outcomes.

e. As a side issue, one of the research members wished to see if a computer simulation model could be developed to evaluate machinery design options which might occur within the harvesting system. In this instance a discrete simulation model was used to analyze the design function itself. This study it was felt would be of particular interest to engineering groups primarily engaged in converting investment monies into physical equipment to be used in the future. This was a short-range analysis of physical alternatives in order to evaluate the different options in design for the different environments in which that equipment might become involved in the future.

f. As the aforementioned work developed, it became apparent that it would be desirable to be able to experiment with changes in financial policies within such a system responsive to the changes in the order-production flow systems or the changes in the physical alternatives which affect the system. Since the money flows within the pulp and paper industry are dynamic over time, a continuous model was used to insure that any producer's particular model could be evaluated. It was felt that this model would be of particular interes to the financial departments of the paper companies, as it specified in great detail the profits and cash flow which might occur as various policies were chosen to accomplish the work evaluated in earlier models. This simulation model could be either a short-range analysis of production and money flows for a given year, or it could be a long-range predictive model of the behavior of the system as it was affected by investment monies.

g. It finally became necessary to look at the routing options for movement from the harvesting site to the mill. Experiments with transportation alternatives were required and a computer model was built to examine the cost alternatives of possible routings. This was primarily a short range, discrete, computation model. It was felt this would be of value to the producer, dealer, and mill procurement segments of the pulpwood industry.

Thus, models reported herein run the gamut of the management function: forecasting, organizing, producing, allocating, designing, evaluating, and routing. All simulation models reported hereafter were presented to the sponsoring organization in such a manner that they could be used by any pulp and paper organization having access to a computer system responsive to the simulation language chosen.

2. Abstracts of Previously Forwarded Reports

The Title Page and Summary or Abstract from each of the previously submitted Theses of Special Research Reports are reproduced on the following pages. The seven works cited include all eight simulation oriented computer programs. Results and instructions in the use of these models maybe found by referring to the individual reports.

A DYNAMO SIMULATION OF LONG-TERM GROWTH OF SOUTHERN PULP AND PAPER INDUSTRY

A THESIS

Presented to

The Faculty of the Graduate Division

by

Pietro Fenu

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in the School of Industrial Engineering

Georgia Institute of Technology

December, 1968

SUMMARY

An important problem facing the southern pulp and paper industry requires decisions pertaining to future investments in land, timber, silvicultural and managerial operations, in the light of changing consumption and productivity levels projected twenty or even thirty years into the future.

The objective of the thesis is to use a dynamic approach to the simulation of the future growth of the pulp and paper industry in the Southern United States.

The study identifies the dynamics of the system as an interrelationship between national economy, pulp and paper industry, and forest management. Through the study of past statistical data and the use of regression equation techniques, it is possible to find rates, factors, and constants necessary for the construction of a "DYNAMO" program. Part of the results obtained concern projections of paper and board consumption, pulpwood requirements and production, on a national and regional scale, covering a period of 50 years. These results are connected with a section of the model concerned with the land policy of the paper companies, in order to highlight the implications of today's policies concerning forest management, over the next few decades.

The projections given by the program, in the form of tabulated data and graphs, are compared with the actual data of the period 1950-1966, in order to establish the validity of the approach. An assessment of the quality of long-run forecasts (up to the year 2000) is made through comparison with other studies in this area.

The main conclusion reached by the study is the forecasted impossibility, by the end of the century, of meeting the requested shares of pulpwood production in the South adopting the present level of individual forest management. All indications point toward a necessary consolidation of land, in order to achieve the economic feasibility and efficient operation of large scale plantations.

A SIMULATION MODEL OF THE SOUTHERN PULPWOOD PROCUREMENT SYSTEM

A THESIS

Presented to

The Faculty of the Graduate Division

by

Leslie Watts Rue

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

November, 1968

SUMMARY

This research was undertaken in conjunction with a research grant awarded to the School of Industrial Engineering at Georgia Institute of Technology by the Southern Executives Association to study the systems and transportation aspects of pulpwood harvesting. The objective of this research was to formulate a scientific basis for determining whether or not the present harvesting system in the South, which is composed largely of independent producers, should be continued over the long run.

The philosophy and techniques of industrial dynamics were applied in this research. The DYNAMO computer simulation language was used to build a mathematical model of the actual system. Simulation experiments on the model led to the formulation of the decision basis sought.

The results of the experiments performed on the model led to the decision that the overall present pulpwood harvesting system must move in the direction of larger company operated harvesting systems. A system composed of large company harvesting operations reacts much faster to changes in mill consumption rates. This system also has a much greater capability for increasing productivity per crew than does the present system.

Because average parameter values were used in this model of the general case, it is strongly recommended that individual mills experiment with this model using data representative of their current procurement system. The results obtained will provide information pertaining to the response capabilities of the

procurement system of that particular mill.

The capabilities of the model are much greater than were exhibited in this research. The model can be used to experiment with almost any phase of the present procurement system.

A Simulation Model for the Common Pulpwood Harvesting Systems of the Southern Pine Region

A SPECIAL RESEARCH REPORT

Submitted to
The Southern Executives Association

by
James Joseph Stark
Walter Wayne Cosby
and
Nelson K. Rogers

Georgia Institute of Technology
Spring, 1969

SUMMARY

The purpose of this report is to form the groundwork necessary for further research and study in the area of pulpwood harvesting and transportation, i.e., to study the basic systems commonly used at present by the majority of pulpwood producers. In order to achieve this objective the following specific goals were attained: (1) characteristics and constraints presently imposed on the common systems of pulpwood harvesting were defined and quantified, (2) three basic systems were defined, and (3) a General Simulation model was developed which is representative of the common 5'3" pulpwood harvesting methods.

The approach used in this study is that of system analysis. The system analysis methodology consists of eight distinct parts: (1) system definition, (2) reticulation, (3) abstraction, (4) identification, (5) measurement, (6) solution, (7) optimization, and (8) validation.

Two conclusions are drawn directly from the sample model. First, the model does represent the system, and second, quantitative insight into the real world system can be obtained from the model with respect to system limiting operations.

DIGITAL SIMULATION MODELS OF FOREST INVESTMENT AND MANAGEMENT

A SPECIAL RESEARCH REPORT

Submitted to
The Southern Executives Association

by

George Anthony Valente, Jr.

Georgia Institute of Technology

April, 1970

SUMMARY

A significant problem confronting the southern pulp and paper industry is decision making in the area of long-term forest management. In particular, the forest must be considered a renewable resource which must be managed in an economical and effective manner.

The objective of this thesis is the development of a technique whereby the individual pulp-producing company can evaluate the level of forest management required to support a continuing demand for pulp from a limited company controlled forest resource. To achieve this goal, separate but related digital simulation models are developed for forest investment and management.

The forest investment model is constructed in the "DYNAMO" computer language. The model is used to evaluate the relative profitability of different forest management treatments on different types of land using rate-of-return on investment as the measure of effectiveness.

Multiple runs of the forest investment model are used in determining a unique cutting sequence for an exhaustive set of different types of land. The sequence is based on a regret function involving incremental changes in rate-of-return.

The concept of the unique cutting sequence is used in developing a large-scale simulation model of a heterogeneous forest resource. Constructed in the "ALGOL" language, the forest management model simulates the dynamic behavior of the forest resource as affected by growth, forest management policies, and harvesting decisions. The model

incorporates the dual objectives of demand satisfaction and profitable investment.

The models are general in nature and allow experimentation with differing sets of parameters, coefficients, and policies. Numerical results are of course dependent on input parameters. Although no policies of optimal forest management are evident from this study, the models are representative of the real-world forest management environment and can be used as a decision making tool by the company engaged in forest resource management.

A GPSS II SIMULATION MODEL TO EVALUATE TERRAIN CAPABILITIES OF TYPICAL PULPWOOD HARVESTING VEHICLES

A THESIS

Presented to

The Faculty of the Graduate Division

by

Bertel Randolph Bertils

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in the School of Industrial and Systems Engineering

Georgia Institute of Technology

September, 1969

SUMMARY

A major problem facing the pulpwood producer is the purchasing of harvesting equipment with appropriate operating options. In view of increasing equipment costs the producer cannot afford mistakes in equipment selection.

The objective of this thesis is to provide the pulpwood producer with a means to evaluate typical pulpwood harvesting vehicles prior to purchase, in relation to their performance in various different terrain conditions.

To accomplish this objective a digital computer simulation model is used to simulate the movement of a typical pulpwood harvesting vehicle across the terrain to be encountered in five pulpwood resource areas within Georgia. General Purpose Systems Simulator II is the simulation language employed in order that the model may be as clear as possible to those individuals unfamiliar with simulation techniques.

In order to construct the computer simulation model, it is necessary to conduct a thorough literature search to determine vehicle mobility characteristics which define a vehicle's ability to negotiate terrain. Likewise the qualities of terrain must be defined in quantitative terms so that interaction between the vehicle and the terrain can be described. It was determined that no widely acknowledged method exists to accomplish the above. The researcher selected the U. S. Army Corps of Engineers Waterways Experiment Station's method of defining terrain and vehicle mobility and added refinements.

The results of the computer simulation show the percentage of the resource areas that the vehicle can negotiate prior to being halted. An analysis of variance is conducted to determine if there is a significant difference in trafficability among the five resource areas and if changing the tire size of the vehicle modelled results in a significant difference in vehicle performance.

The conclusions reached by the researcher are primarily that the simulation model does evaluate a vehicle, that differences do exist between the areas modelled and also that vehicle performance does vary with different tire sizes.

Further research is proposed to provide additional analysis of areas other than those modelled.

THE DEVELOPMENT OF A PULPWOOD PRODUCER'S FINANCIAL MODEL

A SPECIAL RESEARCH REPORT

Submitted to

The Southern Executive Association

by

Nelson K. Rogers

March, 1972

ABSTRACT

THE DEVELOPMENT OF A

PULPWOOD PRODUCERS FINANCIAL MODEL

The objective of this research project is to use the systems approach to create a model for the simulation analysis of pro-forma financial data developed by the typical pulpwood producer in the Southeastern part of the United States. This model is useful to pulp and paper industries, their dealer structure, and independent pulpwood producers in determining the future financial policy option available to a producer of pulpwood as his operation may become more mechanized.

The system model is divided into six sections, as follows:

1. Investment and Debt
2. Desired Assets and Productivity
3. Actual Assets and Productivity
4. Revenues and Expenses
5. Tax Treatment
6. Cash Generation

As the monetary feedback processes and the associated time lags between desired and actual financial policies are critical to the system, an Industrial Dynamics model is used to simulate the system. The model is programmed in DYNAMO computer language and is described in sufficient detail to be comprehended by typical corporate systems analysts.

A COMPUTER COST ANALYSIS TECHNIQUE FOR DETERMINING THE OPTIMUM TRANSPORTATION SYSTEM FROM VARIOUS PULPWOOD HARVESTING LOCATIONS TO A SINGLE PULP MILL

A SPECIAL RESEARCH REPORT

Submitted to

The Southern Executives Association

by

Larry E. Dix

Georgia Institute of Technology

May, 1970

SUMMARY

This research was undertaken in conjunction with a research grant awarded to the School of Industrial and Systems Engineering at Georgia Institute of Technology by the Southern Executives Association to study the systems aspects of pulpwood harvesting and transportation. The objective of this thesis is to study various truck and rail pulpwood transportation systems and develop a method by which a pulpwood mill could evaluate their utility in specific situations.

To accomplish this objective a digital computer model is used to compute the transportation cost of shipping wood from forest landings to the mill by 15 different methods. These methods include various combinations of longwood, shortwood, palletized, unpalletized, truck and rail transportation either from the forest landing directly to the mill or via an intermediate location. The model is not limited to linear relationships but also includes non-linear functions and step functions.

The model developed could be used by a pulpwood mill to study their present transportation situation and to simulate future systems. The input data required is cost information particular to a mill's operating area, the locations of their forest resource areas, and the location of intermediate dealers.

Further research is recommended in this area to include modes of transportation not considered in this study and the expansion of the model to include constraints due to volume.

VIII. OTHER RESEARCH

Naturally all work performed by the research group did not fall under the category of systems analysis or computer simulation of pulpwood production activities. The sponsoring agency was most lenient in allowing the participants to roam where their research interests led them. Three Special Research Reports were submitted in this broader category.

1. Scope of Other Research.

One research assistant with a long work history in reliability of systems in the Air Force desired to translate this knowledge for use by pulpwood producer's and equipment manufacturers. He prepared a Special Research Report on Maintainability considerations at the design stages of developing harvesting equipment. To date this has proved to be the most desired report by members of the sponsoring group. It is interesting to note that this work which was rejected as a Master's Thesis academically is by far our "best seller" to the seventeen sponsoring companies.

Another research assistant, based on his work experience with a sponsoring company, felt that the development of a mathematical model for determination of pulp and paper mill locations in the future was necessary. His mathematical formulation has received considerable academic recognition as a new approach to an old problem. However, no further developmental work by any sponsoring company has enhanced this work at this time.

A final short research work came about as a result of a tremendous amount of library research. It was felt that little had been done to place in one report many of the techniques of scientific decision-making in the management of forest resources. These guidelines for the use of researchers entering the field of harvesting systems was almost lost due to rejection of our "First Annual Report" by S. E. A. counsel. It was however been revised for recent

submission to the sponsor.

2. Abstracts of Previously Forwarded Reports

The Title Page and Summary or Abstract from each of the previously submitted Theses or Special Research Reports are reproduced on the following pages. The three works cited lie perhaps outside the scope of System Analysis but are pertinent to the sponsoring industry. In just these three works alone over one hundred and fifty references are provided in the Bibliographies which have a bearing on the problems of the industry today.

MAINTAINABILITY CONSIDERATIONS FOR PULPWOOD HARVESTING EQUIPMENT

A SPECIAL RESEARCH REPORT

Submitted to

The Southern Executives Association

by

Jimmy L. Bearden

Georgia Institute of Technology

Spring, 1969

SUMMARY

The rapid advances in technology which have occurred during recent years have resulted in machines that perform many tasks much more efficiently than ever before. Such machines, however, are usually complex and are expensive to acquire and operate. Operational costs are affected greatly by the direct and indirect costs of maintaining the equipment. Reliability has become a very important factor in reducing maintenance costs by reducing failure rates. Maintainability is a related factor that is concerned with restoring a system to effective useable condition after a failure occurs. It has not yet received sufficient attention from the manufacturers or purchasers of pulpwood harvesting equipment.

The failure rate of many kinds of equipment may be predicted by use of the exponential distribution function. Analysis of failure data recorded for a power saw is shown to follow such a distribution. In this report, the lognormal distribution is found to be applicable for describing empirical repair time data that was collected for a multifunction pulpwood harvester.

The report indicates characteristics that pertain to reliability and maintainability such as availability, downtime, and the different types of maintenance. Graphical aids are used to describe reliability and maintainability quantitatively.

A MATHEMATICAL FORMULATION FOR LOCATING PULPWOOD AND BULK PAPER MILLS

A SPECIAL RESEARCH REPORT

Submitted to

The Southern Executives Association

by

Richard Callie Kessler

Georgia Institute of Technology

June, 1970

SUMMARY

This thesis presents a method for selecting pulpwood and paper mill locations which minimizes total product cost* under a set of forest resource and market demand constraints. Although both economic and social factors enter into this location decision, only economic factors are included in the mathematical model.

The three main parts of the thesis are (1) defining the factors pertinent to the location decision, (2) mathematically modeling these factors, and (3) deriving a solution technique for solving the model. Defining the factors provides the groundwork for formulating the model. The resulting model is a mixed zero-one integer programming formulation which includes both fixed and variable operating costs. Benders' partitioning and a modified integer programming procedure are presented as a solution technique. The research concludes with an example application of the model and solution technique.

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*Total product cost refers to financial expenditures for stumpage; harvesting; loading; transporting from forest to mill to market; fixed cost such as plant construction, equipment, and taxes; and variable expenses such as labor, power, and water.

A Strategy For Research in Multiple Use of Forest Resources

A SPECIAL RESEARCH REPORT

by

Dr. Joseph Krol

Submitted to

The Southern Executives Association

SUMMARY

The purpose of this paper is to formulate some guidelines that would be useful to research workers entering the field of harvesting systems. These men are in general well educated in the theoretical aspects of systems analysis but often lack the necessary background in forestry.

The area of forest resource utilization is still in its infancy and much remains to be done. This paper reviewed some of the techniques of scientific decision-making in the management of forest resources. The concepts presented have been drawn from the ideas of several interrelated disciplines such as heuristic-oriented mathematics, general system theory, systems analysis, resource system modelling, forest economics and computer simulations. In addition, the policies of a large-scale forest-product industrial concern have been described as an illustration of a practical application of the theoretical concepts.