Project Title: Automation of Scheduling Graphics Procedures

Project No: A-2089

Project Director: Mr. G. L. Peckham

Sponsor: Colonial Pipeline Company; Atlanta, Ga. 30302

Agreement Period: From 12/16/77 Until 1/15/78

Type Agreement: Standard Industrial dated 11/30/77

Amount: $5,313

Reports Required: Final Report.

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Defense Priority Rating: N/A

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Effective Termination Date: 2/9/78 (Final Report delivered)

Clearance of Accounting Charges: by 2/28/78

Grant/Contract Closeout Actions Remaining:

- Final Invoice
- Final Fiscal Report
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other

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CA-4 (3/76)
AUTOMATION OF GRAPHIC SCHEDULING INFORMATION
ENGINEERING EXPERIMENT STATION  
Georgia Institute of Technology  
Atlanta, Georgia 30332

FINAL TECHNICAL REPORT  
on EES/GIT Project A-2089

AUTOMATION OF GRAPHIC SCHEDULING INFORMATION

by

G. L. Peckham and S. S. Lichtman

Prepared for

COLONIAL PIPELINE COMPANY  
Atlanta, Georgia 30326

January 1978
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ABSTRACT

A significant portion of the pipeline schedule preparation time is spent performing manual computations and manual drafting of operating schedules. To effectively deal with projected growth of the pipeline, new capabilities must be developed to provide a more flexible and faster means of producing the operating schedules. The objectives of this study were to analyze the preparation of operating schedules, and to discuss alternatives for the automation of the operating graph, and finally, to recommend the best alternative. The efforts of the study performed the analysis and concluded that the automation of the procedures would be cost effective and provide a flexible means of dealing with change. The approach recommended was the development of software to provide the generation of intermediate plotting points from the present scheduling algorithm and the capability to modify this to reflect current operating procedures.

In addition to short range solutions, an overview of more sophisticated and complex computerized graphic schedule preparation and process control and monitoring systems are presented.
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I. GOALS OF THE STUDY

A significant problem during operations of a long distance pipeline is that of preparing accurate and up-to-date schedules. Schedules are required to provide the dispatchers with information so that they can efficiently control the entire pipeline from one central location. The schedule must provide information such as positions of batches (individual deliveries of different fuel types) during the day, locations of delivery and acceptance of batches to and from the pipeline, and other time and location information critical to the control. Present schedule preparation is predominantly manual with some computerized support provided. Schedule preparation time is a critical problem because new schedules must be started early enough to allow adequate time for their manual preparation. Too much lead time results in the drawing of schedules that require frequent changes. Changes made at one location in the pipeline can easily affect the schedule of the entire pipeline. Therefore, changes made to existing schedules are complex and can cause errors, inefficiencies, and misunderstandings. These problems indicate the need for greater computer utilization during the schedule preparation.

The objectives of this study were to analyze the existing schedule preparation procedures; to provide alternatives to automating the graphics schedules; to provide insights into the technical problems that might be encountered during the automation; and finally, to recommend an approach. In addition, the utilization of more sophisticated graphics capabilities in some application examples were considered.
II. CURRENT COMPUTER HARDWARE AND SOFTWARE

The present computer usage of Colonial Pipeline Company range from special purpose process control applications to Management Information System (MIS) data processing requirements.

The computers range in size from microprocessors (Motorola 6800) to handle conversion of input data for plotters to a large mainframe (Burroughs 6700) used to handle interactive, on-line, Data Base Management System (DBMS) applications and software development. It must be noted that a large portion of the data processing occurs during the 9 a.m. to 5 p.m. interval; except for the process control computers (BUNKER RAMO) which continuously monitor the pipeline operations, the computers are practically idle during off hours.

The B6700 is primarily used to handle all of the MIS data processing requirements (finance, personnel, etc.) and to provide an interactive, on-line scheduling system consisting of a complex scheduling algorithm, a pipeline schedule query system for users, a pipeline utilization forecast data entry system and a schedule update capability used by schedulers. At the time of this study, the B6700 memory was being expanded to provide a more responsive system. The saturation of B6700, due to constantly increasing demands for other applications, make the addition of an on-line graphics display undesirable. Currently, there are plans to off load the B6700 during normal office hours by rescheduling batch processing tasks for processing during evening hours. It is hoped that this will improve the overall system response time.
Computer utilization is of significant importance to future automation because human input is required for any software developed that will produce a plottable graph. Present operations at Colonial require all such software be run during the daytime during the computer peak load period.

Colonial Pipeline currently has a CALCOMP model 763 plotter, which can move the plotter pen in any of 24 different directions with a basic movement size of .005 inches. The plotter operates off-line from the computer with the plot data and associated control commands recorded on magnetic tape. The tape is dumped from a tape drive and interfaced to the plotter. An inhouse installed Motorola 6800 microprocessor is used as the plotter controller to decode the plot data on the tape and supply the X and Y axis drive signals to the plotter, and the pen-up or pen-down (Z-axis) commands. These signals activate step motors to produce an ink-on-paper (pen) plot or drawing. A separate motor controls the movement along each axis. The plotter is capable of operating in one of two modes, namely incremental and ZIP. In incremental mode the smallest movement size is .005 inches, whereas in ZIP mode the plotter can move in steps greater than .16 inches.

Currently, the plotter has been tested with a CALCOMP generated tape dumped from the 9-track, 800 bpi microprocessor tape drive with a 9600-baud serial interface to the 6800. No software package is yet completed to be able to program the plotter. This model plotter is no longer sold and software to support it on the B6700 was never developed. Software to run the plotter was purchased along with the plotter two years ago, however, this software is written in B5500 ALGOL with instream
procedures and will not run on the B6700. One unsuccessful attempt was made to convert the B5500 software to run on the B6700 by Burroughs, however, due to the lack of a market for the CALCOMP 763 and the complexity of the conversion, the effort was recently dropped. The effort lasted over a period of two years and a reported .25 man months was used. In order to use the CALCOMP 763 plotter, either the available B5500 plotter software must be converted or other software that is available for this particular model of plotter, originally developed for another vendor mainframe such as IBM or CDC, must be purchased and converted. Plotter software tends to be quite machine dependent. Although plotter software is frequently written in a high order language such as ALGOL or FORTRAN, a considerable amount of system unique capabilities have been designed into the programs. These features are difficult to replicate on another computer when the programs are converted. The resultant efficiency of the converted code will be, at best, slower than the processing speed of the original programs.
III. CURRENT SCHEDULING PROCEDURES

A. Production of Operating Graph (Refer to Figure 1)

Fifty days before each ten-day scheduling cycle, the product shippers place "nominations" with Colonial for pipeline transportation of their products - refined oil and gasoline. A nomination is a batch of product to be "lifted" into the pipeline at its origination point and "delivered" out of the pipeline at its destination point. Nominations are designated by a batch code and batch size or volume. Batch codes are a string of letters and numbers, usually eight characters long, that provide information about the shipping company, product origination, type of product, cycle to be shipped, and shipments within that cycle. Batch sizes are given in terms of thousands of barrels, with 75,000 barrels being the minimum volume allowed. The initial nominations from all shippers for this cycle comprise the original forecast.

The original cycle forecast is entered into the computer and becomes the "nomination file." As the start of each cycle approaches, many modifications to the original forecast can occur, such as batch deletions, insertions, or changes in volume. The nomination file is correspondingly updated to reflect these changes shortly after they are received. The availability of timely information concerning the shippers' nominations for a cycle is essential to the scheduling procedures performed by the personnel.
Figure 1. Current procedures to produce operating graph
The "coordinator" is the first person to consider the nominated batches of product to be scheduled. He performs a "sequencing" operation on the data which is the key activity of the scheduling procedures. The coordinator uses the most current nomination data available from the computer, information from the previous cycle sequence as a model, locations of lifting and delivery stations along the pipeline in terms of product volume between points, and his own experience in sequencing. Tools available to the coordinator consist of the computer's storage of current and previous cycle batch information, and a desk calculator for volume and pipeline capacity computations. The computer also helps in matching nomination batch codes with the previous cycle's batch codes and storing this information as the new sequence is generated.

Another decision the coordinator makes in his scheduling activity is when "injections" of products should occur at lifting stations. In certain situations it is more efficient to inject a product into the moving pipeline rather than to stop product flow for the entire batch entry.

This process of working the nomination data into a sequence by the coordinator is a difficult task due to the timing problems of two pipeline sections that interact with each other. He must also accommodate changes into the sequence as they occur. The objective of the final operating sequence produced is to maximize the throughput of products in the pipeline.

After the detailed sequence is determined by the coordinator with the aid of the computer, all information is given to a scheduler to convert this information into a graphical representation of the scheduled
activity. This graphical representation is called the operating graph since it is used by the dispatchers in their operation of the pipeline. It is considered to be the final result of the scheduling process. This manual process has been used throughout the company's history.

The creation of the operating graph by the scheduler is a long and tedious process, since he must manually draw and label each line representing product movement and identify the product. One operating graph will span a period of three or four days of pipeline activity, which may involve about 100 different batches of product. Due to the nature of pipeline operation, a change of activity in one section of the pipeline can have an effect upon batches upstream and downstream from the change. This causes a major revision of the operating graph by the scheduler which can take, in some cases, a whole day. If changes are allowed to occur near the cycle start, an entire completed operating graph could be invalidated and rendered unusable by the dispatchers.

During the drafting process, the scheduler will use the detailed sequence information developed by the coordinator and pumping rate data, which is an intermediate output of the computerized scheduling algorithm. These pumping rates suggest a desired product flow depending upon line conditions, pumping constraints, and type of product (gas or oil). The scheduler performs time and volume calculations with this data. He is also able to interact with the updated nomination file to take into account any changes which may have occurred since obtaining the sequence from the coordinator. The final result of his efforts is the operating graph.
B. Use of Computerized Scheduling Algorithm

A scheduling algorithm that runs on the B6700 provides cyclic pipeline scheduling information. The algorithm is quite complex and has evolved from many years of development and fine tuning. Although the scheduling program has been rewritten many times, the basic concepts and algorithms first developed over fourteen years ago still exist. The more recent inclusion of DMSII, Burrough's data base management system, and the shippers' on-line schedule accessibility has caused major changes to the scheduling computer programs. Some of the more sophisticated modules, such as the optimizing injection/lifting algorithms, have yet to be modified to operate in the DBMS environment. Consequently, the current results of the scheduling programs provide only a crude estimate of the actual schedule. The output of the scheduling algorithm is what pipeline shippers query to determine what schedule to expect within the next cycle or the next few days. The scheduling program results appear to be used only by the schedulers to determine pumping rates during the drawing of and calculation of data for the operating graph.

The results of the scheduling programs deviate from current scheduling practices (operating graphs) not only because of yet-to-be incorporated (converted) software, but also because the running time of the scheduling programs prohibits it from being rerun frequently enough to reflect the most recent nomination (schedule) changes. On the other hand, manual preparation of the operating graph does not necessarily keep up with changes either. Current practice indicates that it is easier to erase pencil lines on the graph than to rerun the entire long running
scheduling algorithm to update the data base. Therefore, many changes occur after initial schedules are prepared and are not incorporated into the interactive data base; however, they might be incorporated into the operating graph.
IV. ALTERNATIVE PLANS FOR AUTOMATION

The alternatives to automatic production of operating graphs vary in complexity and, hence, in cost from one extreme of providing a completely automated schedule to the other extreme of providing automatic drafting capabilities to the scheduler. The alternatives include (1) upgrade scheduling algorithms, (2) computerized mini-algorithms, and (3) modification of plotting parameters file.

A. Upgrade Scheduling Algorithm

Because the scheduling algorithm provides only general operating schedules data, additional programming is required to make the output representative of current operating procedures. This alternative requires the enhancement of the present scheduling algorithm and the development of additional software to produce data that can easily be translated into plottable data. Once the modification of the algorithm is completed, a program must be written that will utilize software plotter modules to produce a plotter tape. The plotter tape would be used as input to plot and produce the operating graph.

This alternative may require more man hours than most alternatives but it seems to be an ultimate requirement for the future. Present manual methods of preparing the operating graph may seem adequate, but as the complexity and the number of spurs, pipeline miles, etc., become greater, less time will be available to manually prepare operating graphs.
Advantages: The advantages of upgrading the scheduling algorithm are increased accuracy and a reduction in the scheduler personnel requirements (or at minimum, freeing personnel to analyze and monitor scheduled versus actual pipeline performance.) The data would be significantly more accurate if shippers retrieve the results from the data base. The programs for producing the plotter tape could operate directly on the data base with minimal operator interaction. The plotter tape could be produced during the evening hours with a batch run, and the plot could be produced off line the next day by using either the plotter or (if a tape unit is built in), the Lockheed MAC 16 computer.

Upgrading the scheduling algorithm also offers the additional advantages of an easily transformed schedule data base that could be used in more sophisticated graphic displays or accessed from dispatcher operating consoles. Data accurately reflecting the operating graph could be provided through query access from the data base to the dispatchers. This would enable dispatchers to modify the schedule to reflect sudden major changes in the availability of shipper products; this could be a significant advantage if the change occurs during off hours when scheduler assistance is not available. Current practices require dispatchers to "manage somehow" until the next regular work day when schedulers come back to work. Three-day holiday weekends could result in significant pipeline throughput losses when major changes arise and quick, possibly inefficient, decisions are made.

Disadvantages: The cost of developing software which reflects current operating practices will be significant. Algorithms that provide crude approximations to the actual schedule take a considerable amount of processing time to run, assuming they must be run during the day.
Sophisticated software that can produce an accurate operating graph could approach the size, running time, and complexity of the present scheduling algorithm that may take as long as one working day to provide one pipeline schedule. If such a system were to be added to the existing running programs under present operating conditions, adequate response time would be questionable.

The present long running algorithm, we believe, could be significantly shortened through major redesign. This would be expensive and take many man months to complete. It must be noted that a five to one improvement (wall clock processing time) is gained when the scheduling programs are run during evening hours. During this time the algorithms are not competing for computer resources with other users. Considerable system user awareness and prioritizing requirements for computer resources is recommended to alleviate expected computer saturation.

B. Computerized Mini-Algorithms

Numerous computerized mini-algorithms could be developed to increase the speed of data calculations. These computer tools would be provided through interactive software algorithms. These algorithms would not merely be sophisticated hand calculators; instead they would be sufficiently complex to automate individual portions of the scheduler's calculations. For example, a mini-algorithm could be developed to determine which batches can fit within a schedule "window" when given a starting point within the sequence. This calculation requires many repetitive additions and comparisons.
Advantages: Each algorithm would be used repetitively to replace time consuming hand calculations. The small individual programs for each algorithm could be quickly designed and programmed. The programs could be tested and provided to the schedulers for use as they were developed. As each tool becomes available, it could be provided for test and use. This would permit almost immediate benefits. This alternative could be considered an immediate step to Alternative A in which each of the tested, computerized tools is combined with others to form a heuristic, automated system. The mini-algorithms would permit considerable flexibility in that human decision making and experience would be utilized throughout the preparation of the schedules. The smaller, shorter running algorithms may permit the utilization of one smaller minicomputers such as the on site MAC 16 or an additional dedicated minicomputer instead of the B6700. It may be possible to program some algorithms into table mountable, programmable hand calculators or microcomputers.

Disadvantages: Considerable personnel time still be required to prepare operating graphs. If the B6700 system is used, present computer saturation may make the mini-algorithms too slow to use or at least slower than hand calculations.

Unless each algorithm has comprehensive tutorial instructions, training must be conducted on their usage. Training must be given to the users so that they can obtain confidence in the use of the algorithm. Without this training the computerized tools will become ineffective and not reach their full potential.
C. Modification on Plotting Parameters File

This alternative plan for automation uses the current computerized scheduling algorithm to produce an operating graph plotting program to drive the computer-controlled digital plotter and draw an operating graph that represents the scheduling algorithm results. To make this graph acceptable for use by the dispatchers, a scheduler will determine what changes in the initial graph are required and interact with the computer's data file of plotting parameters to incorporate those changes. At the time before each cycle when the scheduling information changes are minimal, a final automatic plot of the operating graph will occur and be given to the dispatchers for use.

This approach can be accomplished by implementing computer programs and defining user procedures to perform various tasks. First, the results of the scheduling algorithm must be obtained and converted into a minimal data set required to automatically plot each product's movement through the pipeline. This data set, the plotting parameter file, consists of a data structure of related information for each product, which defines how the product should be graphically represented. For example, at the initial lifting of a product, the lifting bar's starting and ending coordinates, in terms of time and location, must be stored in the plotting parameter file. Likewise, the line that represents the product's movement must have its endpoints stored in the file. The entire geometry of the operating graph can be represented in this fashion.
The next major processing task required is to have a set of computer routines to actually plot the operating graph. These routines must use primitive graphical operations that position the plotter and draw vectors and characters. Macro graphical routines may use a combination of the primitive operations to draw frequently used objects, like a lifting or delivery bar. The highest level of software is the applications programming that processes the plotting parameter file's data structure and maintains logical relationships between products to be plotted.

Since the current scheduling algorithm does not produce results that are directly usable by the dispatchers, modification capability of this initial graph is required. Therefore, the final set of procedures involve a user-computer interaction that edits or changes the plotting parameter file. This interaction could be in the form of a control language where the user identifies the data structure to be changed and provides the new data. The computer routines will perform the editing functions and determine what effect this change may have upon the other product's data structures in the file. If additional modifications are to be made, the computer can inform the user of these and allow him to approve any automatic modification procedures.

Once a final plotting file is obtained with little or no modifications required, a finished operating graph can be automatically plotted and given to the dispatchers for use.

This alternative of computer-aided user modification of the plotting parameter file has certain advantages and disadvantages.

Advantages: The production and modification of intermediate plot data provides a flexibility that would capitalize on human processing capability and provide a means of bridging the gap between effort being
put into the improving scheduling algorithms and current operating practices. As the scheduling algorithm is improved, the modification of data could be reduced with a target of eventual elimination of data modification requirements, except in the cases of last minute, major changes. The modification software should provide a greater capability than just the changing of plot points. Instead, it should allow the operator to specify major change with simple commands. For example, the insertion of a lifting at one point, or the movement of a lifting from one time to another, can be facilitated through simple, interactive instructions. The software would have enough "intelligence" to modify all points downstream or upstream depending upon the nature of the change. In this alternative, batch programs could be used to transform the intermediate plot data back into the data base, making available up-to-date data.

Disadvantages: Unless powerful software is produced to intelligently interface with meaningless plot points, the schedulers will begin to feel they are drawing lines using computers and not producing efficient, optimal operating schedules. Again, computer availability may preclude adequate response times to support interactive processing of this additional load on the system. The development of modifying or fine-tuning software may be less cost effective than to incorporate this capability into the original scheduling algorithm and to look for ways to improve its running time.
V. CONCLUSIONS and RECOMMENDATIONS

Current increases in scheduling data handling requirements will require increases in scheduling personnel in the near future. The study of present manual preparation of operating graphs has led to the conclusion that the process can be automated through the use of the computer and a plotter. The automation will significantly improve scheduling procedures and provide a responsive and flexible means to deal with change. The efforts of this study and considerations of the feasibility and costs associated with each of the alternatives lead to the conclusion that Alternative C is the best approach for automating the graphic display of pipeline scheduling information. Alternative C is, therefore, recommended.

Based upon the above recommendation, phases of development to accomplish the automation of the operating graph are proposed in Appendix A. Future, potential uses of graphics within the pipeline schedule preparation and operations are briefly discussed in Appendix B.
APPENDICES

A. Phases of Development to Automate Operating Graph Plotting

B. Long Range Graphics Applications
APPENDIX A

PHASES OF DEVELOPMENT TO
AUTOMATE OPERATING GRAPH PLOTTING

Phase 1 - Develop plotter capabilities required for drawing operating graphs.

Such capabilities would include lines, bars, alphanumeric characters and symbols at various angles and sizes.

Phase 2 - Develop applications programming to plot operating graph from output of computerized scheduling algorithm.

This involves determining what information is required to plot the graph, how to access that information, and plotting procedures to actually draw graphs.

Phase 3 - Develop applications programming to allow modifications to be made to the operating graph as produced by the computer algorithm so the final graph is adequate for use by dispatchers.

As discussed in Alternative C, this application program would allow scheduler computer interaction to manipulate the data base of plotting parameters used as input to the program in Phase 2.
Phase 1 - Plotter Operation

Phase 1 involves developing the basic plotter capabilities required to draw a complete operating graph. Therefore, an analysis of the operating graph's basic elements must be made to determine what graphical, alphanumeric, and color elements are currently used.

1. Basic Elements of Operating Graph

a. Graphics
   - Dark Lines - approximately 1 mm. thick
   - Light Grid Lines - less than 1 mm. thick; horizontal and vertical
   - Horizontal Bar - approximately 5-7 mm. thick; variable length

b. Alphanumerics
   - Characters - all letters and numbers; written on an angle capability
   - Special Symbols - hyphen; decimal point

c. Colors
   - Black - graphics and alphanumerics
   - White - background of paper
After the basic elements are determined, a decision must be made concerning the operation of a plotter to attain these capabilities. The existing plotter, a CALCOMP Model 763, has no operating software to perform basic plotting functions. Therefore, Table I presents alternatives for the development or acquisition of an operational plotter to complete Phase 1.
TABLE I

ALTERNATIVES FOR PLOTTER OPERATION

1. Using the existing model 763 plotter, convert 5500 ALGOL to 6700 ALGOL in plotting package provided by CALCOMP.

2. Use a CALCOMP FORTRAN plotting package which is compatible with the Burroughs 6700 FORTRAN compiler to drive the model 763 plotter. Operation would be in the off-line mode with the magnetic tape dumped from the 9-track, 800 bpi tape drive.

3. Use a CALCOMP FORTRAN plotting package which is compatible with the MAC 16 FORTRAN compiler to drive the model 763 plotter. Operation of the plotter is the same as in 2.

4. Buy the new model 1037 CALCOMP plotter (see Table II) for $8,000. Develop the required software to drive this plotter using the Burroughs 6700, or MAC 16, in off-line operation.

5. Buy the new model 1037 CALCOMP plotter with interface and complete software package that CALCOMP has designed for the Burroughs 6700, or MAC 16, for $10,720. On-line or off-line operation should be possible. No basic plotting utility software need be developed in-house.
TABLE II

NEW PLOTTER DATA

CALCOMP Model 1037
- incremental plotter
- 34" width plotting area
- 120' rolls
- DC servo motors - 12 ms pen delays
- nylon-tip and ball-point pens
- Cost of plotter alone - $8,000
- Requires an interface either bought from CALCOMP or Burroughs

CALCOMP 906 plotter controller includes:
- interface and software for Burroughs 6700 computer
- allows for on-line operation of plotter
- software includes built-in character and line generators

Total Cost - plotter model 1037
- interface - 906 controller
- 1 year maintenance - parts and labor

$10,720

(Maintenance cost $1,000/year afterwards.)
Following is a list of commercially available plotter and plotter software vendors. Phase 1 should take into consideration the long-range plans for graphics applications, and select the initial equipment with this in mind.

**Mechanical Pen Plotters:**

Applicon  
Broomal Industries  
Calcomp  
Data Technology  
Gerber Scientific  
Glasser Data  
Haag - Streit  
Houston Instrument  
Soltec  
Xynetics  
Zeta

**Electrostatic Devices:**

- Gould
- Kratos
- Varian
- Versatec

**Software Packages:**

- CALCOMP
- DISSPLA
- GCS
- GINO-F
- GPGS
- Tektronix PLOT-10
Phase 2 - Automatic Plotting of Operating Graph

Phase 2 involves developing the application program to plot the operating graph from the results of the computerized scheduling algorithm. Therefore, an analysis of the operating graph's data elements must be made to determine what graphical, alphanumeric, and color data elements are currently used.

1. Data Elements of Operating Graph

a. Graphics

- Time - vertical axis of grid in terms of half-hour increments
- Distance and Pipeline Volume Capacity - horizontal axis of grid in terms of 10,000 barrel increments
- Product Movement - darker lines at any possible angle
- Delivery, Lifting, and Injection of Product - horizontal bars

b. Alphanumerics

- Station Locations - code for delivery, lifting, and booster stations along pipeline
- Batch Code and Size - when product enters the graph at origination of movement line
- Volume Capacity Values - for Y-axis at strategic points along pipeline
- Time Values - for X-axis at strategic points in graph, such as the beginning and end of liftings and deliveries
- Flow Rate Values - at strategic points along product movement lines
- Injections - written out near delivery station bar where occurring

c. Colors - No color data used.

The operating graph plotting program would have the required data elements as input. It is currently believed that the scheduling algorithm is capable of providing these data elements and a complete operating graph could be generated. However, modifications are required to this graph so it can be made more useful to the dispatchers for pipeline operation.

Figure 2 represents the general system flowchart for Phase 2. Besides having routines to access the algorithm results data base, additional routines may be required to convert that information into the basic plotting parameters.

This plotting parameter file is used as input to the operating graph plotting program which uses the plotting utility package developed in Phase 1. The output of the plotting program is interfaced to the plotter either off-line or on-line, depending upon the decisions made in Phase 1.

A representation of an automatically plotted operating graph is shown in Figure 3.
Figure 2. System Flowchart to Plot Operating Graph
Figure 3. Representation of automatically plotted operating graph
Phase 3 - Scheduler Modification of Operating Graph

Modification would occur on the plotting parameter file rather than running the scheduling algorithm over again to obtain new results. Therefore, a human is still needed to decide what change should occur in the schedule and what effect it has on the current operating graph. The programs would deal with the operating graph geometry aspects and allow changes to be made in this geometry. The programming problem is now one of computer-aided design rather than pipeline operation. A scheduler is needed to make decisions, but the computer still does all the drawing aspects of producing an operating graph.

Figure 4 is a flowchart of scheduler/computer interaction to indicate the software routines that need to be developed to achieve the required modification capability. The scheduler is the key decision maker in a feedback loop of updated operating graphs. He knows what the current graph looks like when a change in the schedule arrives. He decides what changes need to be made to this current graph's geometry, and relates these changes to a modification program. The modified parameters are then given to the plotting program developed in Phase 2, and the modification cycle repeats itself.
Figure 4. System Flowchart to Modify Operating Graph
Timely and accurate information communicated to and from various personnel and processes is necessary for effective scheduling and control of pipeline operations. The pipeline operating graph considered in this report represents one information medium transferring information from shippers to dispatchers, with many scheduling procedures and data processing tasks intervening. Other forms of data transfer are possible to provide information. Presented in the following discussions are some long range graphics applications that propose some of these additional information transfer tasks in which computer graphics hardware and techniques are applied. Additional development for these applications would be in the high level programming effort and not in the routines to drive the plotter or interface with the host computer.

A computer-controlled plotter with appropriate programs is very useful for management information applications. In many management reports, information is represented in graphic form as two or three-dimensional plots, bar charts, pie charts, diagrams and schematics. Most of the data that is required to construct these graphics resides in the computer's database. Therefore, a graphical management information reporting package could be designed and implemented to access the required data in the computer and generate the appropriate graphic with the plotter.
Another graphics application that requires investigation is a geographic map representation to show the existing or proposed routes of the pipeline. Various maps would be automatically plotted showing information about the pipeline, such as lifting, booster, and delivery stations, pipeline load constraints, pumping constraints at each booster, and distance and time information at different points. The computer system can easily change the scale of the map to provide for close-up displays of locations. This system can be very useful for both control and planning of pipeline operation.

A new range of applications evolves when a graphics output and input terminal is introduced along with a hardcopy plotter. With this capability, the user can display graphical data and make modifications to it before a plotted output is obtained.

Timely modifications to the pipeline operating graph could be performed easily by a scheduler if graphics terminal and modification software were used. The applications program could provide for interactive computer updating of the data file used to plot the operating graph and allow the scheduler to see preliminary versions of the operating graph before a copy is made for the dispatchers. Changes in the nomination data can be accommodated, along with injection decisions, to make the operating graph up-to-date and useful. Besides the easy user modification of graphs before they are to be plotted, the graphics terminal configuration can be used for other, more sophisticated real-time applications.

A real-time product movements, monitoring system would receive current pipeline information from the process-control computers at each booster station and the MAC 16 supervisory system computers. This
information would give the current location of each product batch in the pipeline for "batch-tracking" capability. A graphical monitoring system could represent this real-time data in the operating graph format and display it over the graphics terminal screen along with the scheduled operating graph (see Figure 5). A glance at this display would show the actual vs. scheduled position of an inline batch at the present time. Also, a predicted batch movement path could be forecast and displayed as an extension of the actual path.
Figure 5. Real time batch monitoring system display
Real-time product movement information could be represented another way by using the pipeline geography concept to display the existing route pictorially. Within the pipeline diagram, each product batch can be distinguished with a batch code or symbol. They could be in different colors if that capability is available on the graphics display used. The product batches would move down the screen in real-time, just as they do in the pipeline. This allows the dispatcher to easily monitor the pipeline activity. Lifting and delivery stations are shown at their locations along the pipeline along with the products scheduled to enter or leave.