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Abstract: This report examines scheduling sensitivity analysis and studies the effects that time and cost have on critical and potentially critical tasks in a rigid real-life project. The model project is in the production phase of its life cycle. The concentration of this analysis pertains to the outcomes of overall tasks and project cost, based on carefully controlled experimental procedures and the application of time and cost models for tasks of interest. An experimental procedure was developed and utilized in producing a strict method in manipulating certain tasks. It was determined that, for a well-defined project with a fixed finish date, small variations in the timing of change orders and stoppages that affect significant tasks can lead to large cost increases to the overall project.

PROJECT SCHEDULING SENSITIVITY ANALYSIS

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EMP-P9101

PROJECT SCHEDULING
SENSITIVITY ANALYSIS

for

ADVANCED PROJECT MANAGEMENT
EMGT 510P

DR. DUNDAR F. KOCAOGLU

JUNE 5, 1991

by

TOLGA CHANDIR
TIM DUGAN
DOUG LEE
VINCENT SCALESSE
BOB YAGHMAIE

EXECUTIVE SUMMARY

"PROJECT SCHEDULING SENSITIVITY ANALYSIS"

for EMGT 510P

by
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This project is a scheduling sensitivity analysis, studying the effects that time and cost have on critical and potentially critical tasks in a rigid real-life project. The model project is in the "production" phase of its life cycle. Most of the concentration of this analysis pertains to the outcomes of overall task and project cost based on carefully controlled experimental procedures and the application of time and cost models for tasks of interest. It is important to note that the use of the term "sensitivity analysis" is not intended to imply optimization of the overall project performance. Rather, it is an attempt to pin point the areas within the work breakdown structure where significant alterations in the timing of scope changes and delays cause crashes and cost variations of the overall project.

Initially, it was imperative to choose a project upon which meaningful results can be obtained from the analysis. A realistic project, design and installation of a paper machine rebuild, was chosen. The project's work breakdown structure consisted of sixty-four tasks. Seven of the sixty-four tasks were examined while time and cost variables were changed. Once the project was chosen, one significant step was to find an appropriate project management software package. It was determined that the package needed to allow for activity-on-node (AON) network graphs, critical path identification (i.e., CPM), and Gantt chart entry and display.

Detailed time and cost models were developed and the methods and procedures to apply them to the selected tasks were determined. An experimental procedure was developed and utilized in producing a strict method in manipulating certain tasks. In producing this procedure, the analysis was validated by the derived time and cost relationships represented by a family of curves. The summary of the findings was made followed by conclusions that were produced after examining the data. It was determined that, for a well-defined project with a fixed finish date, small variations in the timing of change orders and stoppages that affect significant tasks can lead to large cost increases to the overall project.

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1. INTRODUCTION

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2. BACKGROUND

2.1 Paper Machine Rebuild Project.

2.1.1 **Description:** The project chosen for analysis was an actual construction project being managed by one of the group members. The project consists of the rebuild of a section of a paper machine at a nearby paper mill. The project was chosen due to the complex relationships between tasks including several network paths.

The scope of the project calls for the design and installation of a new calender stack and associated systems. A calender stack is the section of the paper machine where the sheet of paper is finished to the desired quality specifications. The stack is made up of two steel rolls supported by frames on each end. Precise process control is possible due to an internal hydraulic system in one roll and a hot water heating system in the other. The sheet of paper passes between these two rolls which form the sheet into a uniform thickness, or caliper, and also impart finish qualities such as smoothness.

Several support systems are also required. These include a variable speed drive system, a threading system, and a profiling system. The drives are used to turn the rolls while the machine is operating. Very precise speed control is required. The threading system is used to thread the sheet of paper around the various rolls. It is needed when the machine is starting up as well as when a paper break occurs during normal running conditions. The profiling system is used to "fine tune" the paper qualities, making it possible to produce a high quality sheet of paper. It is used continuously during machine operations and is computer controlled through a feedback loop.

2.1.2 **Summary**: There are 3 major parts to this project. First is the procurement of the major equipment. For the purposes of this analysis, we are looking at the project after the equipment selection process has been completed. The major equipment has already been placed on order and is being manufactured. The second part of the project is the design work for the installation of the equipment. A consultant engineering firm will be used. This firm must communicate regularly with the machinery vendors to insure that certified drawings are issued in a timely manner. If any corrections are required, these must be incorporated into the construction drawings. The third part of the project is the installation. This part has been broken into two phases: pre-installation and shutdown work. The pre-installation will begin as soon as the construction engineering package is complete. The major equipment would not yet be on site. The shutdown work would begin when the pre-installation is complete and the major equipment has been delivered.

2.1.3 **Execution**: All of the systems described above are required before the new calender stack can be commissioned. The major pieces of equipment will be ordered from a vendor. The vendor will design and fabricate the equipment then deliver it to the paper mill. The calender stack has a long lead time for manufacture. This allows the installation design work to be done before the equipment delivery. Smaller pieces of equipment, such as motors, starters, and pumps, would be specified and ordered during this engineering phase.

All parts are required well before the major equipment arrives since the installation will be phased. The first phase, pre-installation, consists of work that can be accomplished without affecting the machine operations. Obsolete systems can be demolished and removed, new piping systems can be installed and electrical wiring can be installed. Any required tie-ins would be accomplished during regularly scheduled machine shutdowns which occur monthly.

The second phase of the installation is when the existing calender stack will be removed and the new stack and associated systems will be installed. This will require an extended machine shutdown which must be scheduled months in advance. If this date were to slip due to late equipment deliveries, the entire mill would be affected. Typically, several other jobs would be taking place concurrently. These would all have to be rescheduled to accomodate this project's schedule.

2.2 Project Management Software.

The following facts affected our decision to choose Microsoft Project as the software package.

- It was the software package that was readily available.
- It allowed us to work in the Windows environment. This way three of our five group members were able to work on the software.
- Working in the Windows environment gave us the opportunity of using Microsoft Excel as the spreadsheet which was beneficial, especially in drawing the graphs.
- It used a network analysis method - CPM - quickly and easily.
- The program itself was very user friendly which allowed us to perform our experiments efficiently.
- It was very easy to obtain Gantt charts and networks by defining the activities and their time, cost, and precedence constraints.
- It was easy to make changes in the work breakdown structure.

2.3 Network Analysis Technique.

Project scheduling is the time-phase arrangement of the project activities subject to precedence, time and resource constraints in order to accomplish project objectives.[B] Network analysis is the major part of the project scheduling. CPM (critical path method) and PERT (project evaluation and review technique) are the most widely used network analysis techniques.

In choosing our analysis method we considered the pros and cons of the CPM and PERT methods.

CPM is the deterministic approach to the network problems as the activity durations are considered to be a certain value. The primary goal of a CPM analysis of a project is the determination of the critical path.[B] As a consequence of fixed activity durations the project completion time is also fixed. Though this approach is simple and easy to use, it does not reflect the real world conditions exactly.

PERT recognizes that the duration of an activity can not be known with certainty in advance.[TW] So PERT takes the uncertainties in activity durations into account. By defining the most likely, pessimistic and optimistic activity completion times a probability distribution of activity durations is derived. A beta distribution is assumed for activity durations. PERT is also concerned with the completion of the critical path within the deadline and the probability of the project completion is equal to the probability of completing the critical path. PERT deals more with the real world problems by considering the uncertainties but it also has some shortcomings in:

- Requirement of three time estimates
- Inappropriateness of beta distribution
- Oversimplification of estimation formulas

- Violation of Central Limit Problem
- Determination of critical path.[B]

The Central Limit Theorem says that the means of a large number of independent random variables will be approximately normally distributed. PERT assumes normal distribution for the total project time but the analysis does not always satisfy the assumptions.

In most networks there is a positive possibility that a path other than the one with the longest completion time will, in fact, be critical [N]. The problem occurs when the expected value of path completion time is greater for the critical path, but the probability of on time completion is lower for the non-critical path [TW]. Besides the paths, completion times can not possibly be independent as a result of common activities in the paths.

CPM is an easy to use and simple method with the consideration of fixed durations which may not always reflect the true durations. Although PERT is more realistic in considering the durations, it has several important shortcomes which are hard to solve. The problems associated with PERT make this method more complex and difficult to deal with. So we chose the more simple method, CPM, for our analysis.

We not only analyzed the activities on the critical path but also considered the non-critical path activities which may ultimately turn out to be the critical activities due to some internal or external changes.

3. MODEL DEVELOPMENT

3.1 Time and Cost Model Descriptions.

In modeling the relationships of time increase and cost variations on specific tasks within the project, separate time functions and cost functions are developed depending on where a change occurs relative to the amount of the task completion time. It is assumed that the duration factor is equal to the overall task completed. This is, if the duration of a task is set for 10 days, then the task is considered half complete after 5 days corresponding to a "DF" of 0.5. This does not imply that a task is judged on progress by means of the percentage of allocated resources consumed. No specific reference is made to resource allocation in deriving these models solely from the fact that the tasks of interest are contracted outside of the company. The main concern is characterizing overall time and cost as negotiated with the contractor.

So, each family of curves developed will be of similar form, but with different constants for each particular task analyzed. The independent variables include the timing of a change order (scope change), the occurrence of unscheduled work stoppages, and variations due to labor and material intensive aspects of tasks. The modeling of these relationships are simplified into linear representations for ease of development and analysis. However, the trends these curves exhibit more than serve their purpose for the scope of this analysis.

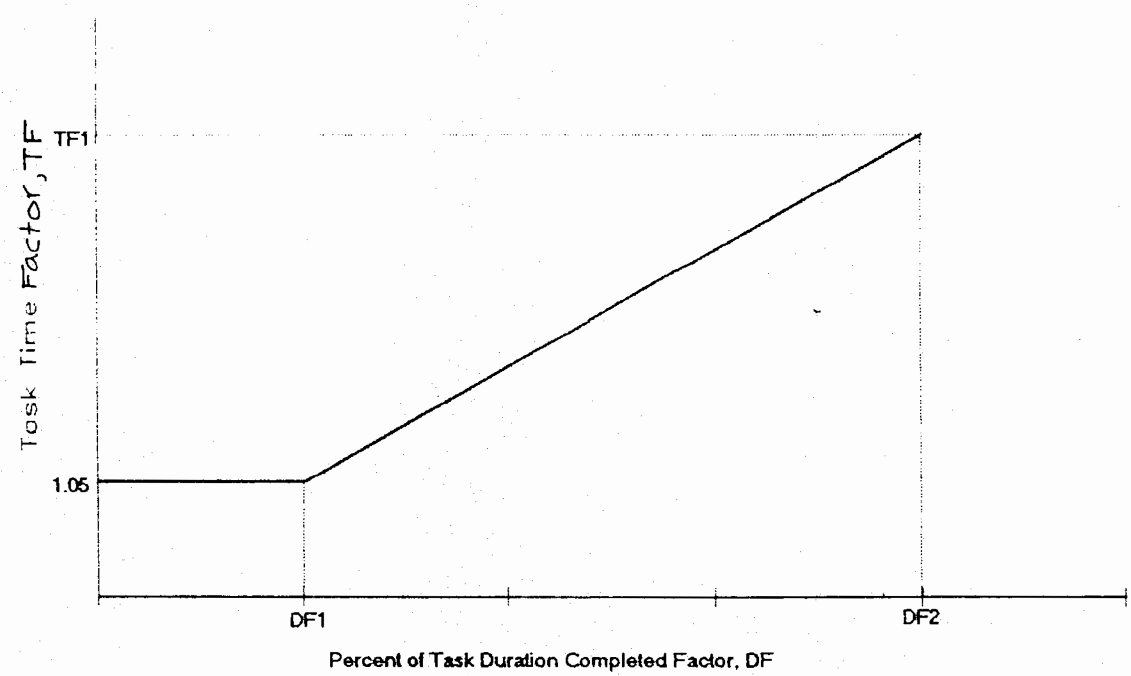
Concentrations of modeling development was limited to a small number of variables. Specific tasks are characterized by the same general functions, but with different data point references to take into account their particular idiosyncrasies. These general functions consist of time and cost curves for a task scope change of 5% and for a work stoppage of 150%, and cost curves for crashing of labor intensive tasks. A general description of each form is given below, while the specific models for the analyzed tasks are located in Appendix B.

The premise of all the models derived in this study are based on an increase of overall task time and cost according to the percentage of the task completed when the problem occurs. A percent time completed versus increase of time factor as well as percent time completed versus increase of cost factor concept is applied throughout the graphs.

3.2 Modeling for Change Order.

For the scope change variable, an arbitrary fixed degree of 5% is applied. Basically, this places an inherent minimum 5% time (and cost) increase to the task as shown below in the % time vs. time factor graph.

FIGURE 1. Time Increase Model for a 5 Percent Change Order



If a change order should occur from 0 to DF1 percent completed of the task, only a 1.05 factor is applied to the overall task time. However, if the task is further along, past DF1, considerable more time may be forthcoming to compensate for major rework. A scope change in this context implies some degree of re-design, change of design specifications, etc. Of course, in any engineering activity, if weaknesses in the design are found early in the design cycle, corrections can be made with small delays impacting the schedule. Whereas, re-design at later stages of the cycle make for significant delays. This increase of the time factor begins at points beyond DF1. There is also a "cut-off" point for which beyond this change orders are forbidden, represented by DF2. Each task in which this curve applies will possess unique DF1, DF2, and TF1 values.

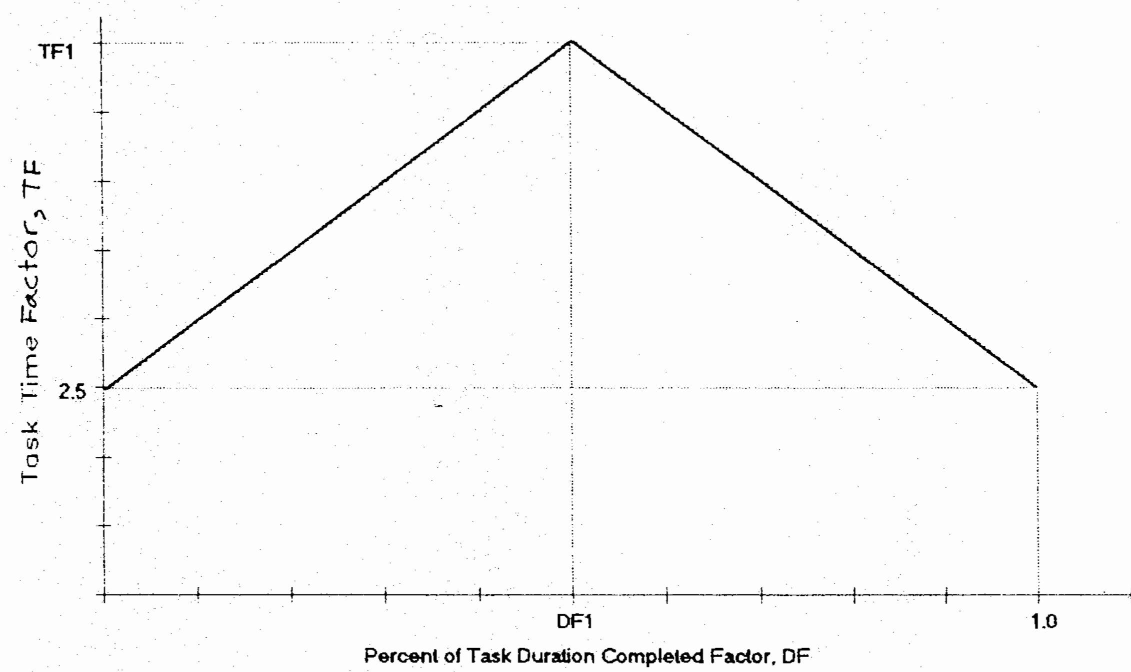
To relate a cost curve to a 5% scope change, a simplified model is applied that identically tracks the trend of the time function. The rationale behind this derivation is the fact that costs for labor, equipment, and material are constant throughout the task, thus, increase in time causes a one-to-one affect on the costs ensued. More sophisticated models could be utilized but this serves the purpose for the study.

3.3 Modelling for Unscheduled Work Stoppage.

An unscheduled work stoppage can potentially become a factor in causing due to various reasons as labor strikes or delays in predecessor tasks. In such cases, the importance again lies in the timing of the occurrence of stoppage. A fixed period of a stoppage may in some cases add more than this period of the original tasks duration. Depending on the percentage of the task completed, a stoppage could be compounded from the fact of re-mobilization of equipment and of labor resources. Availability of these resources (more required further into the task) is a source of much potential delay. The model below resembles this concept with the maximum time factor peaking during the middle stages of the task. As the task reaches the completion point, the work is winding down and a stoppage would have the less affect and approaching just the addition of the fixed period of the stoppage. In this model a delay of 150% is applied to this case. Therefore, a 150% stoppage at 0% completion of a 1-day long task results in an effective 2.5-day duration (a factor of TF=2.5) of the task. Specific stoppage models are included in Appendix B.

The cost function for stoppage is assumed to be identical to the time function. The rationale behind this is the fact that costs for labor, equipment, and material are constant throughout the task. Thus, increase in time causes a one-to-one affect on the costs ensued. More sophisticated models could be utilized but this serves the purpose for the study.

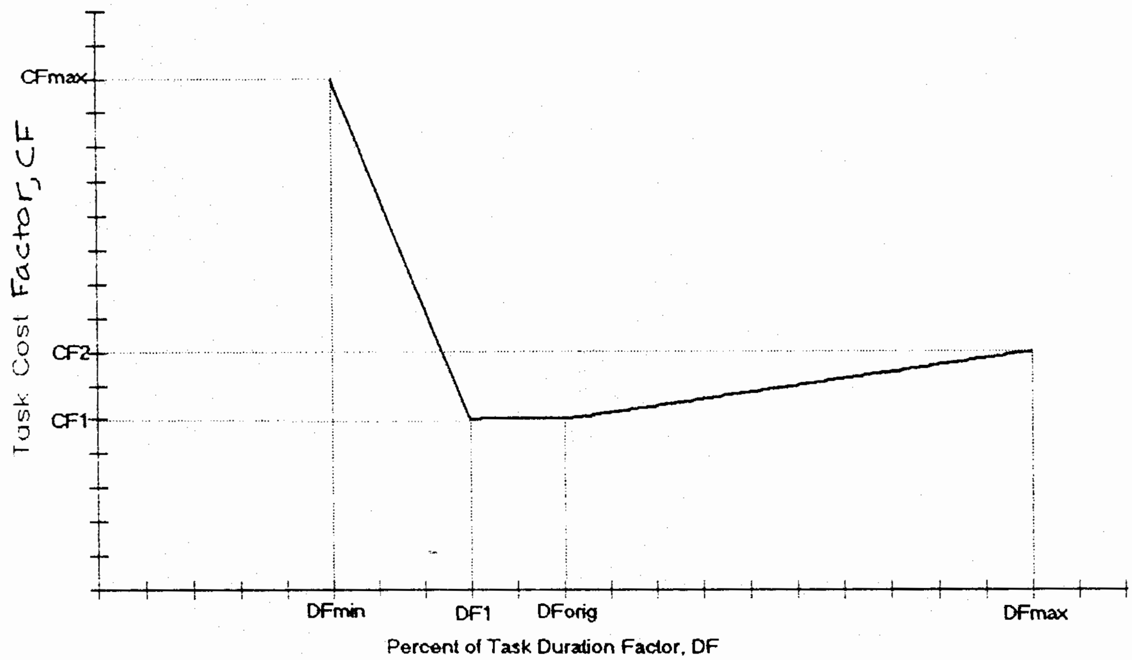
FIGURE 2. Time Increase Model for a 150% Work Stoppage



3.4 Modelling for Labor Intensive Task Crash.

When a particular task's duration is increased within a project with a fixed finish date, certain tasks on the critical path might need to be crashed. By crashing a task, the fixed endpoint of the project is preserved while other tasks are being extended. Below is a model of task duration factor, DF, versus task cost increase factor, CF. All of the labor intensive tasks in the paper machine project are contracted out, and project management overhead is not being tracked. In this model the main application is for the crashing of labor intensive tasks. The overall cost scale depicts the dominance of the increased labor resources and wages that are ensued upon shortening or lengthening of the task duration. Of course, the representation of the crashing portion of the curve below could more accurately be shown in some non-linear form.

FIGURE 3. Cost Increase Function for Labor Intensive Task



With each given task there is always an absolute minimum duration time. Any time duration less than this, DF_{min}, is physically impossible. For DF_{min} there is also a maximum cost, CF_{max}, associated with the crash. As the crash time is set to a duration close to the original duration, DF_{orig}. but less (between DF1 and DF_{orig}) the original contracted cost of the task is applied. As the duration of the task is extended past DF_{orig} toward a maximum allowed duration, DF_{max}, the overall task costs increase linearly due to hour rates of the contractors. Keep in mind that the y-axis is the cost factor that would be multiplied by the original cost to obtain the overall resulting costs.

4. PROCEDURE

4.1 Choose Tasks to Analyze.

4.1.1 For Change Order Analysis: The largest equipment manufacture items were chosen, Manufacture Stack (task 32) , Manufacture Threading (task 36), and Manufacture Drives (task 44).

4.1.2 For Stoppage Analysis: The longest and most costly labor-intensive tasks were chosen, with special attention to those which were on the critical path or could become so with some stoppage. Remove Obsolete System (task 49), and

Pour Concrete Foundations (task 50) were the longest; Install New Equipment (task 61) and Piping (task 63) were quite high in cost due to their very short duration.

The intent of the analysis was to cause changes in tasks 32, 36, 44, 49, and 50 which will cause crashing of tasks 61 and 63.

4.2 Set Up Project Model.

4.2.1 **Check Constraints:** Microsoft Project allows several types constraints for the beginning and end of a task. For instance, one can constrain a task so that it "must start on" a particular date. Begin Shutdown (task 57), which is on the critical path between the independent tasks to be lengthened and the dependent tasks to be crashed, is originally constrained to start exactly on a particular date. In order for our analysis to work, we had to release that constraint and allow the task to be started "as soon as possible". We also had to constrain the end of the project to end on a particular date. These were not unrealistic modifications, since the plant startup (end of project) is more time critical than the plant shutdown timing, although both are very important.

4.2.2 **Filter Project:** To make the analysis quicker, the work breakdown structure (WBS) was "filtered" to show only the analyzed tasks.

4.3 Perform Change Order Time Analyses on Manufacture Equipment Tasks.

4.3.1 **Determine Crash Point:** Starting with task 32, the task duration was increased in increments of one week until the software warned that a particular task was being overlapped. The task times can easily be changed by merely highlighting the duration field of the analyzed task in the WBS part of the screen and typing the new duration. Then the duration was decreased in smaller increments (.1 weeks) until the message stopped appearing. Finally, the duration was increased in even smaller increments (.01 weeks) until it appeared again. This point is manually recorded. The corresponding duration factor (DF) for that time increase factor (TF) was calculated and recorded later. See the Appendix A for the TF versus DF curve for task 32 with a 5% change order.

4.3.2 **Crash Downstream Tasks:** The task referred to in the warning note was task 63. However, since both tasks 61 and 63 were being analyzed, both were crashed equally. First, task 32 was lengthened from the crash point by .1 week. Then tasks 61 and 63 were decreased equally in increments of 0.5 hours until the message stopped appearing. The new duration of task 32 was manually recorded, along with the new durations of tasks 61 and 63. Then the duration of task 32 was increased by 0.1 week again. This caused tasks 61 and 63 to be crashed beyond the minimum duration of 6 hours, 50% of the original 12 hours. Tasks 32, 61 and 63 were returned to their durations at the last data point, and task 32 was increased by .02 weeks and the same procedure for crashing tasks 61 and 63 was followed, recording the durations that resulted. Finally, the "maximum" crash point was determined by the same iterative procedure that the initial crash point was determined.

The same procedure was used for a change order on task 36. Task 44 did not have enough slack to be lengthened by the minimum TF of 1.05 (see Appendix A), so its analysis was aborted.

4.4 Perform Stoppage Time Analyses on Labor Intensive Tasks.

4.4.1 **Determine Crash Points:** One more modification had to be made to the project model. A gap of 28 days was inserted between task 50, Pour Concrete Foundations, and all successors, for concrete curing. Even with this gap,there was a large amount of slack for tasks 49 and 50, so a stoppage of 150% was chosen. The same iterative procedure as above was used to find the crash points.

4.4.2 **Crash Downstream Tasks:** The above iterative procedure was used to find three points on the crash curves of tasks 61 and 63 for stoppages of tasks 49 and 50.

4.5 Perform Cost Analyses.

4.5.1 **Determine Duration Factors:** For all of the recorded times, the corresponding TF's were calculated. Then the corresponding DF's were determined from each of their time functions. A spreadsheet was used for these calculations.

4.5.2 **Determine Cost Factors:** For all of the calculated DF's, the corresponding Cost Factors (CF) were calculated with a spreadsheet.

4.6 Summarize Overall Cost Vs. Duration Factor.

All of the overall task cost increases were calculated and summed in a spreadsheet, shown in Appendix C. They were tabulated as a function of the independent task duration factor for either a 5% change order or a 150% stoppage. Figures 4 and 5 summarize overall project cost change as a function of the duration factor when a 5 % change order occurs in the equipment manufacture tasks. The bold numbers indicate when crashing costs are being incurred.

FIGURE 4. Overall Project Cost Change
Vs. Timing of 5% Change Order on Task 32

DF(32)	O.A. PROJ CHANGE
0.00	$37,500
0.20	37,500
0.22	41,250
0.239	44,813
0.240	45,000
0.258	78,375

FIGURE 5. Overall Project Cost Change
Vs. Timing of 5% Change Order on Task 36

DF(36)	O.A. PROJ CHANGE
0.00	$3,000
0.70	10,500
0.72	10,800
0.732	10,980
0.745	22,376
0.746	41,190

Figures 6 and 7 summarize overall project cost change as a function of the duration factor when a 150 percent work stoppage occurs in the labor intensive tasks.

FIGURE 6. Overall Project Cost Change
Vs. Timing of 150% Stoppage on Task 49

DF(49)	O.A. PROJ CHANGE
0.000	15,000
0.340	32,000
0.354	32,700
0.368	33,400
0.374	63,500

FIGURE 7. **Overall Project Cost Change Vs. Timing of 150% Stoppage on Task 50**

DF(50)	O.A. PROJ CHANGE
0.000	15,000
0.240	27,000
0.244	27,200
0.248	47,400
0.250	57,500

5. DISCUSSION AND CONCLUSIONS

The original model behaved very rigidly. The heart of the system is the task labeled as 'Major equipment', which is the time and cost core of the project. In order to gain a more workable model, we decreased both durations and costs associated with the main activities under this task. Major equipment' task still accounts for 84% of the total cost ,and ,it's duration amounts to 91% of the total project duration.

The model has behaved rationally ,and has used up all the resources that were made available to it for the project tasks.

The model has found the critical path, i.e. the longest possible path to complete the project, by CPM analysis. This is basically an optimization by maximizing total project duration. A search for cost minimization has not been the intent of this project. In fact, the model response to introduction of change orders and stoppages, which will lead to an increase in cost was studied. Had we looked into the cost minimization, the results would have suggested differently. As the bulk of the project deals with the manufacturing of the machinery, a good engineering work during the design phase and a scrutinized process of machinery selection would support management attempts to reduce costs. In fact, engineering is the only part of the project which is handled in-house, and so the management will be able to closely plan and control this task. However, it does not make a considerable portion of the total project cost. The balance of the project is sub-contracted out to number of firms. The management should be paying utmost attention in choosing the main sub-contractors for the machinery ,since their commitments will have to be seriously counted on for a successful project completion on time, per specified requirements, and within the budget.

The external change imposed on the model is occurrence of change orders and encountering stoppages due to uncontrollable external parameters. This in turn results in lengthening of the tasks which are under the particular change order or stoppage effect. This lengthening of duration was then passed on to the tasks down the road and we studied the effect of crashing applied to these successor tasks.These are all either non-critical tasks such as #60 (modify existing systems) and #62 (Wiring) or tasks that were on the critical path such as #61 (install new equipment) and #63 (piping). In doing this we soon realized that the originally imposed constraints on the 'Equipment assembly' task #55 had to be released. This task was originally scheduled to be started on a given date, we had to change it to start as soon as possible instead.

The model provides a graphical tool for studying the effect of change orders and stoppages. These changes have different consequences on each task. It is recommended that the management plan ahead for encountering such sudden changes. When the first signs of a possible change is eminent they should try to channel the actual realization of the change to the proper stage in the task duration. The time and cost consequences will be greatly dependent upon the timing of the change with respect to the task time history.

The model shows available slacks for the Engineering task (see Appendix A). This resource shall be utilized in a timely and efficient manner to prepare the technical requirement of these expected changes.

The model also illustrated the changing of the critical path as each of the analyzed tasks were lengthened. Appendix D shows these changes. Note that it is actually possible to have two critical paths simultaneously if a non-critical task's total float is completely used up by lengthening the task and the end point of the project is kept constant.

Another sensitive area in the project plan is the specified time for the shut-down of the operating plant(task #57). Delays to this task will be very costly and will have sever negative effects on the marketing and customer oriented considerations. Manufacture selection is quite crucial to warrant a timely shut-down as scheduled. Also the management should create a good contingency plan to resort to in case of emergency. Strict penalty clauses shall be foreseen in the contract to account for possible violation of schedule in relation to these serious and expensive mile-stones.

The successor tasks were crashed to minimum possible time and the associated crash costs were calculated. An interesting observation is made regarding the cost implications. Take the application of a 5% change order to task #32(manufacture stack). This change extended the task duration from 32 weeks to 34.08. The successor tasks #61 and 63 were crashed to their minimum time of 6 hours each. The maximum total cost increase to the project is $78,375 (i.e. at DF=0.258). Of this total cost increase 61% is due to the change order effect on the main task #32, and 39% is due to crashing of the successor tasks #61 and 63 to keep the total project on schedule. Although task #32 is measured in weeks and tasks 61 and 63 in hours, this does suggest that the task inter- dependencies in the network will come into action for a change to any specific task and will share the magnitude of the final outcome.

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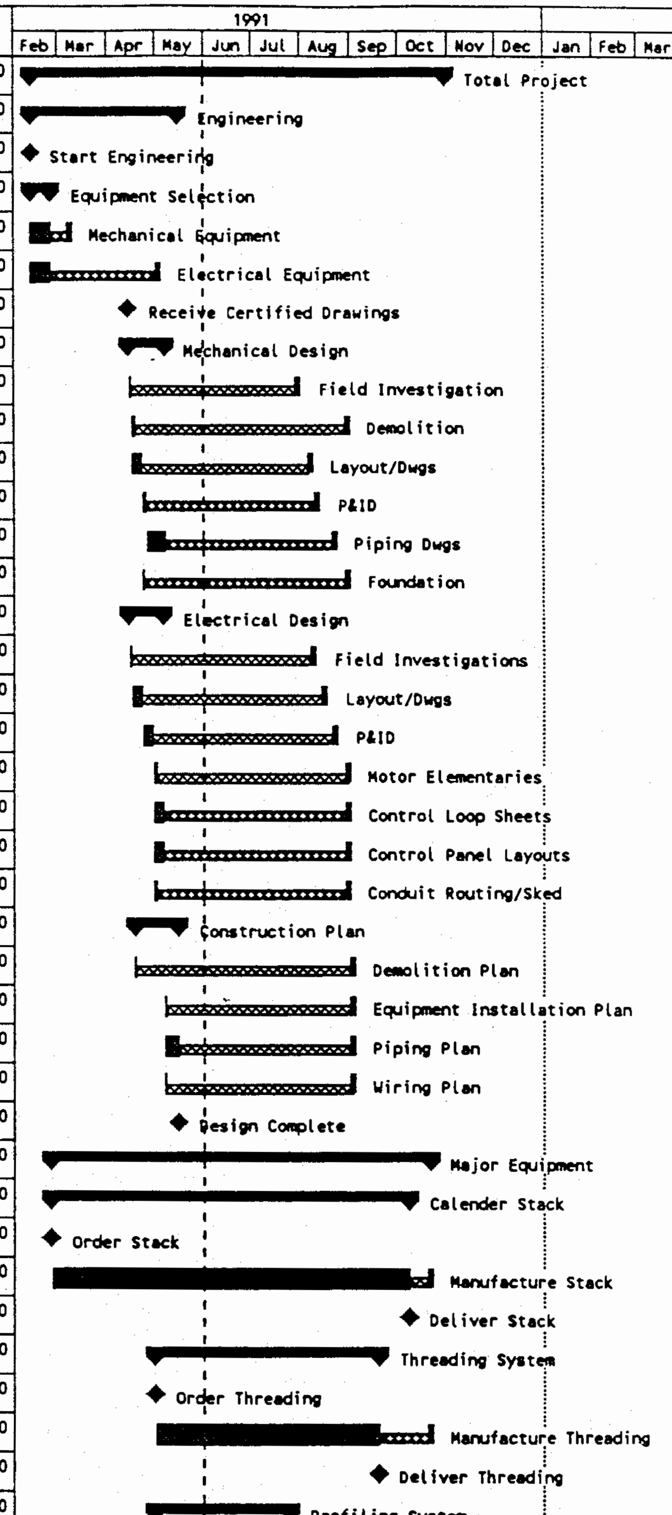
[N]: S. Nahmias: Production and Operations Analysis; Irwin 1989; pp. 339-381.

[TW]: R. A. Toell and J. Witherspoon: "From Managing the Critical Path to Managing Critical Activities"; Project Management Journal; Dec. 90 No. 4 Vol. XXI, pp. 33-36.

APPENDIX A. PROJECT GANTT CHART

ID	Name	Duration	Cost
1	Total Project	260.29ed	$1,309,684.00
2	Engineering	93.38ed	$35,184.00
3	Start Engineering	0d	$0.00
4	Equipment Selection	13.38ed	$10,000.00
5	Mechanical Equipment	2w	$5,000.00
6	Electrical Equipment	2w	$5,000.00
7	Receive Certified Drawings	0d	$0.00
8	Mechanical Design	22.17ed	$7,596.00
9	Field Investigation	1d	$708.00
10	Demolition	2d	$840.00
11	Layout/Dwgs	5d	$1,680.00
12	P&ID	3d	$1,512.00
13	Piping Dwgs	7.5d	$2,520.00
14	Foundation	1d	$336.00
15	Electrical Design	21.38ed	$10,788.00
16	Field Investigations	1d	$1,044.00
17	Layout/Dwgs	5d	$1,680.00
18	P&ID	5d	$2,688.00
19	Motor Elementaries	3d	$1,008.00
20	Control Loop Sheets	5d	$1,680.00
21	Control Panel Layouts	5d	$1,680.00
22	Conduit Routing/Sked	3d	$1,008.00
23	Construction Plan	28.38ed	$6,800.00
24	Demolition Plan	1d	$500.00
25	Equipment Installation	1d	$1,260.00
26	Piping Plan	7.5d	$2,520.00
27	Wiring Plan	1d	$2,520.00
28	Design Complete	0d	$0.00
29	Major Equipment	237.63ed	$1,100,000.00
30	Calender Stack	224.63ed	$750,000.00
31	Order Stack	0d	$750,000.00
32	Manufacture Stack	32ew	$0.00
33	Deliver Stack	0d	$0.00
34	Threading System	140.63ed	$60,000.00
35	Order Threading	0d	$60,000.00
36	Manufacture Threading	20ew	$0.00
37	Deliver Threading	0d	$0.00
38	Profiling System	84.63ed	$200,000.00



Project: Calender Stack Insta
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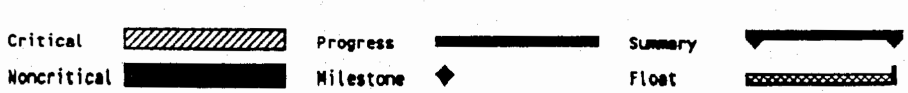
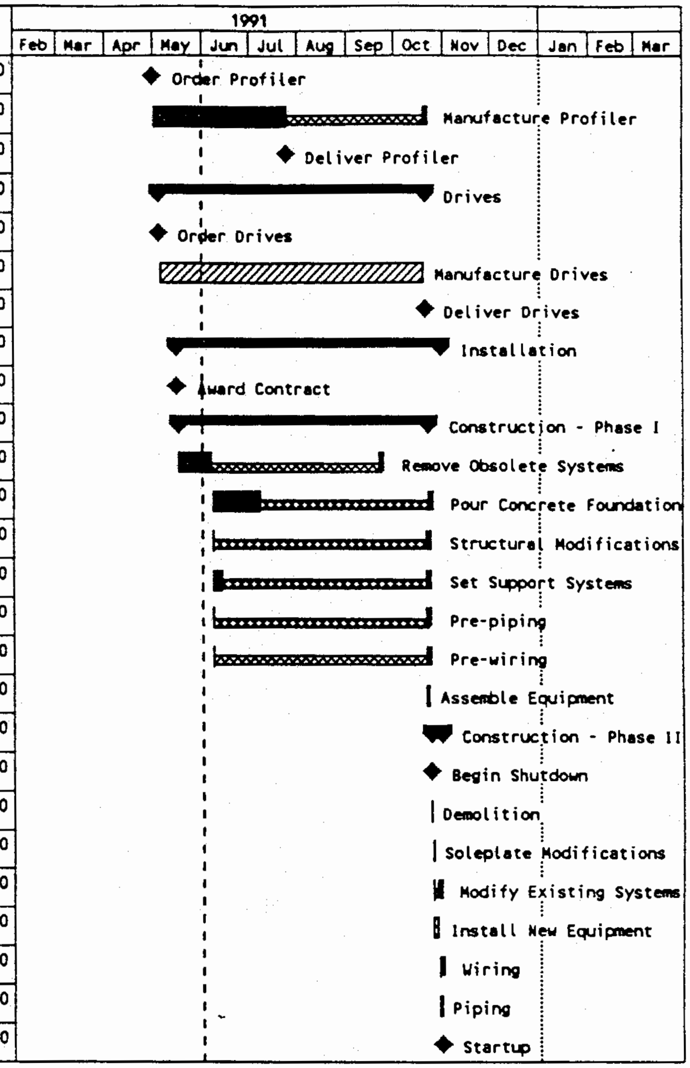


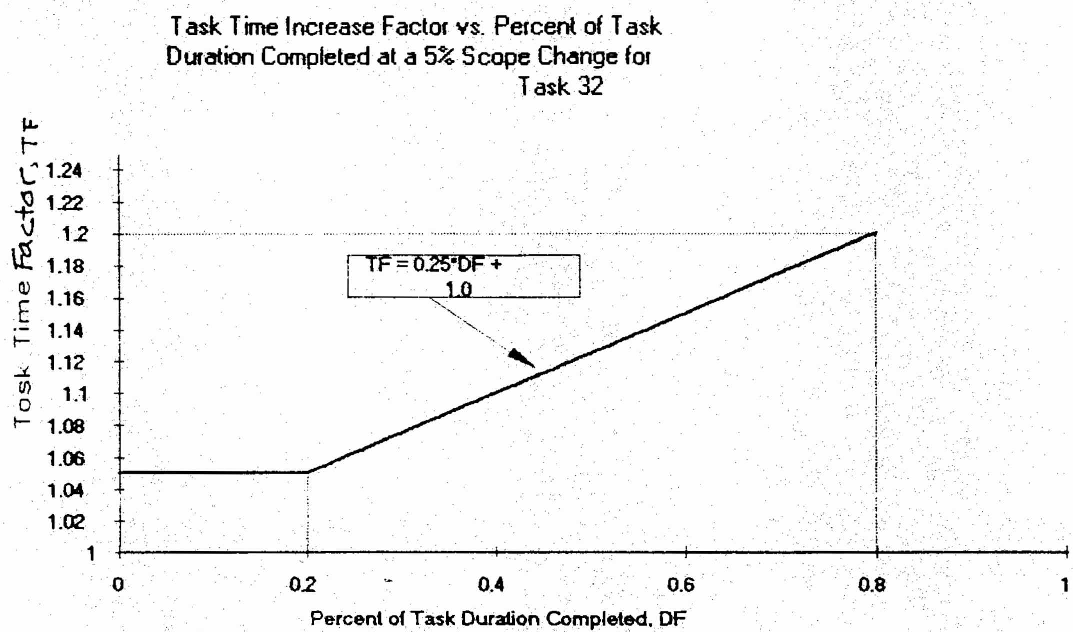
ID	Name	Duration	Cost
39	Order Profiler	0d	$200,000.00
40	Manufacture Profiler	12ew	$0.00
41	Deliver Profiler	0d	$0.00
42	Drives	169.33ed	$90,000.00
43	Order Drives	0d	$90,000.00
44	Manufacture Drives	24ew	$0.00
45	Deliver Drives	0d	$0.00
46	Installation	166.92ed	$174,500.00
47	Award Contract	0d	$0.00
48	Construction - Phase I	159.38ed	$29,500.00
49	Remove Obsolete Systems	15d	$10,000.00
50	Pour Concrete Foundatio	30ed	$2,000.00
51	Structural Modification	1d	$3,000.00
52	Set Support Systems	5d	$2,500.00
53	Pre-piping	1d	$5,000.00
54	Pre-wiring	1d	$5,000.00
55	Assemble Equipment	3d	$2,000.00
56	Construction - Phase II	6.29ed	$120,000.00
57	Begin Shutdown	0d	$0.00
58	Demolition	6h	$20,000.00
59	Soleplate Modifications	1d	$5,000.00
60	Modify Existing Systems	8h	$25,000.00
61	Install New Equipment	12h	$50,000.00
62	Wiring	8h	$10,000.00
63	Piping	12h	$10,000.00
64	Startup	0d	$25,000.00

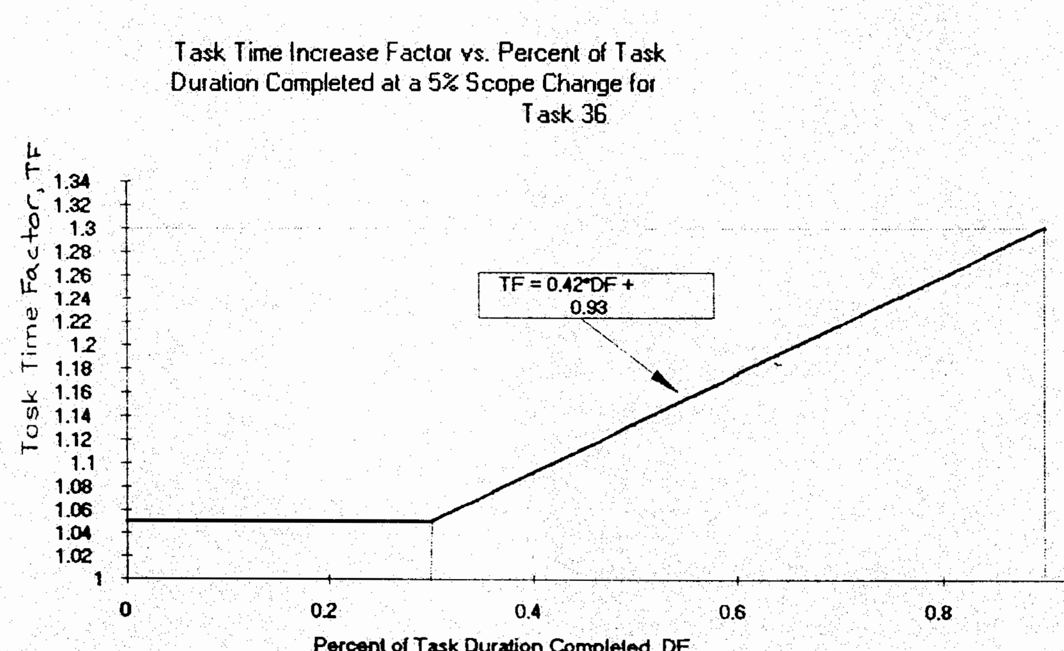


Project: Calender Stack Insta
Date: 5/31/91

Critical / Noncritical / Progress / Milestone / Summary / Float

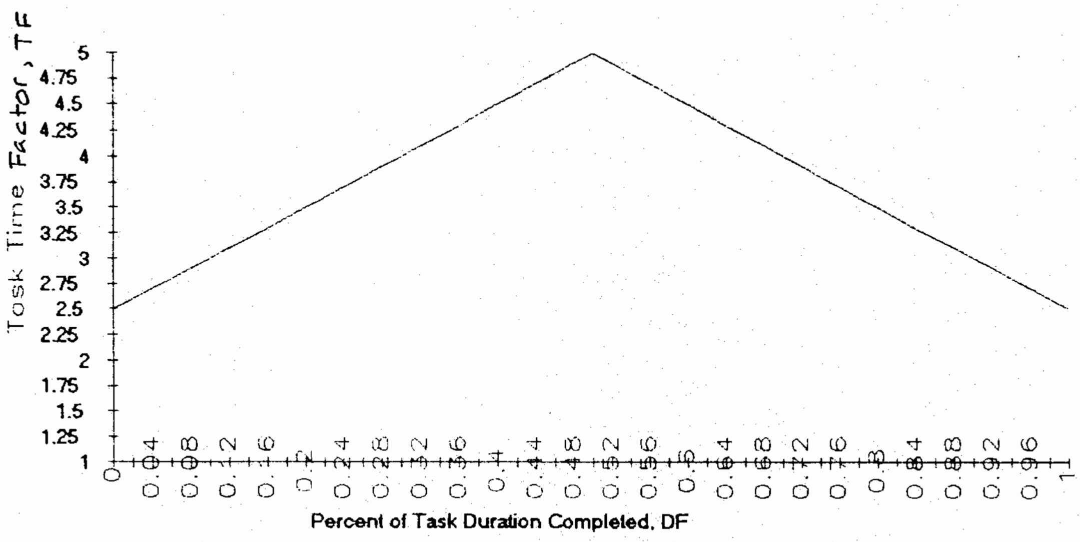
APPENDIX B. SPECIFIC TIME AND COST FUNCTIONS



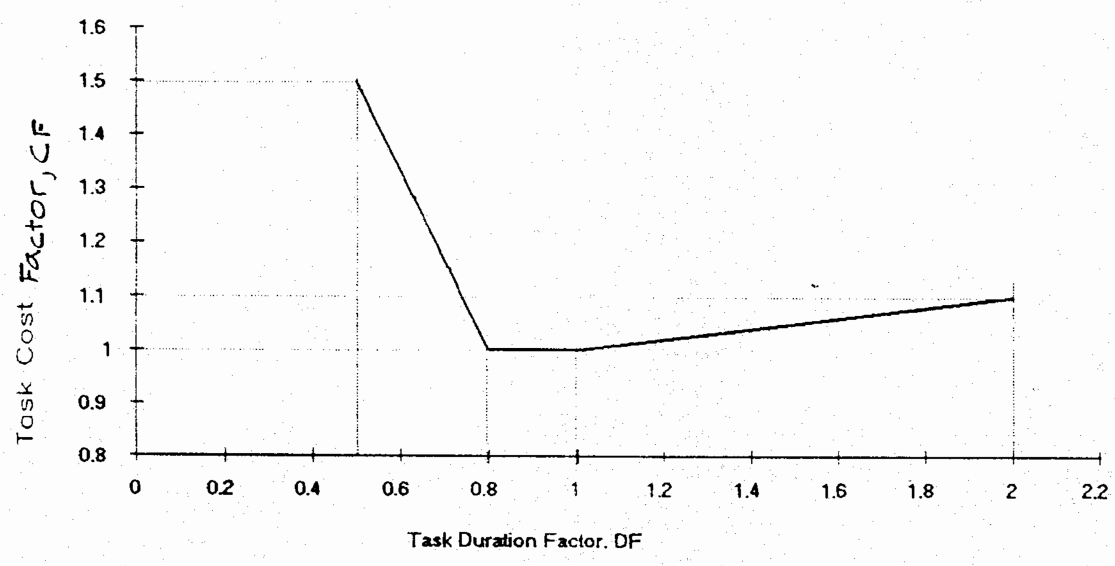


NOTE: CF vs. DF CURVES ARE IDENTICAL TO TF vs. DF FOR A PARTICULAR TASK

Task Time Increase Factor vs. Percent of Task Duration Completed for a 150% Work Stoppage for Tasks 49 and 50



Cost Increase Factor vs. Task Duration Factor for Tasks 61 and 63



APPENDIX C. TIME AND COST DATA
(Bold Numbers Indicate Crashing Has Occured)

IMPACT OF A 5% CHANGE ORDER ON
TASK32

TASK 32					
DF	TF	CF	O.A. TIME	O.A. COST	CHANGE
			32 WKS	$750,000	$0
0.00	1.00	1.00	32.00	750,000	
0.20	1.05	1.05	33.60	787,500	37,500
0.22	1.06	1.06	33.76	791,250	41,250
0.239	1.0598	1.0598	33.91	794,813	44,813
0.240	1.0600	1.0600	33.92	795,000	45,000
0.258	1.0645	1.0645	34.06	798,375	48,375
0.26	1.07	1.07	34.08	798,750	48,750

RESULTING IMPACT ON TASKS ON
CRITICAL PATH:

TASK 61					
DF (32)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$50,000	$0
0.00	1.00	1.00	12.00	50,000	0
0.20	1.00	1.00	12.00	50,000	0
0.22	1.00	1.00	12.00	50,000	0
0.239	1.00	1.00	12.00	50,000	0
0.240	0.90	1.00	10.80	50,000	0
0.258	0.50	1.50	6.00	75,000	25000
	CRASHED TO MINIMUM TIME				

TASK 63					
DF(32)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$10,000	$0
0.00	1.00	1.00	12.00	10,000	0
0.20	1.00	1.00	12.00	10,000	0
0.22	1.00	1.00	12.00	10,000	0
0.239	1.00	1.00	12.00	10,000	0
0.240	0.90	1.00	10.80	10,000	0
0.258	0.50	1.50	6.00	15,000	5,000
	CRASHED TO MINIMUM TIME				

IMPACT OF A 5% CHANGE ORDER ON TASK 36

TASK 36					
DF	TF	CF	O.A. TIME	O.A. COST	CHANGE
			20 WKS	$60,000	$0
0.00	1.05	1.05	21.00	63,000	3,000
0.70	1.18	1.18	23.50	70,500	10,500
0.72	1.18	1.18	23.60	70,800	10,800
0.732	1.1830	1.1830	23.66	70,980	10,980
0.745	1.1863	1.1863	23.73	71,175	11,175
0.746	1.1865	1.1865	23.73	71,190	11,190
0.76	1.19	1.19	23.80	71,400	11,400

RESULTING IMPACT ON TASKS ON CRITICAL PATH

TASK 61					
DF (36)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$50,000	$0
0.00	1.00	1.00	12.00	50,000	0
0.70	1.00	1.00	12.00	50,000	0
0.72	1.00	1.00	12.00	50,000	0
0.732	0.854	1.000	10.25	50,000	0
0.745	0.688	1.187	8.26	59,334	9334
0.746	0.500	1.500	6.00	75,000	25000
	CRASHED TO MINIMUM TIME				

TASK 63					
DF(36)	TF	CF	O.A. TIME	Q.A. COST	CHANGE
			12 HRS	$10,000	$0
0.00	1.00	1.00	12.00	10,000	0
0.70	1.00	1.00	12.00	10,000	0
0.72	1.00	1.00	12.00	10,000	0
0.732	0.854	1.000	10.25	10,000	0
0.745	0.688	1.187	8.26	11,867	1867
0.746	0.500	1.500	6.00	15,000	5,000
	CRASHED TO MINIMUM TIME				

IMPACT OF A 150% STOPPAGE ON TASK 49

TASK 49					
DF	TF	CF	O.A. TIME	O.A. COST	CHANGE
			15 DAYS	$10,000	$0
0.000	2.50	2.50	37.50	25000	15000
0.340	4.20	4.20	63.00	42000	32000
0.354	4.27	4.27	64.05	42700	32700
0.368	4.34	4.34	65.10	43400	33400
0.374	4.37	4.35	65.55	43500	33500

RESULTING IMPACT ON TASKS ON CRITICAL PATH

Task 61					
DF (49)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$50,000	
0.000	1.00	1.00	12.00	50,000	0
0.340	1.00	1.00	12.00	50,000	0
0.354	1.00	1.00	12.00	50,000	0
0.368	0.950	1.000	11.40	50,000	0
0.374	0.500	1.500	6.00	75,000	25000
	CRASHED TO MINIMUM TIME				

Task 63					
DF (49)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$10,000	
0.000	1.00	1.00	12.00	$10,000	0
0.340	1.00	1.00	12.00	10,000	0
0.354	1.00	1.00	12.00	10,000	0
0.368	0.950	1.000	11.40	10,000	0
0.374	0.500	1.500	6.00	15,000	5000
	CRASHED TO MINIMUM TIME				

IMPACT OF A 150% STOPPAGE ON TASK 50

TASK 50					
DF	TF	CF	O.A. TIME	O.A. COST	CHANGE
			15 DAYS	$10,000	
0.000	2.500	2.500	37.50	25000	$15,000
0.240	3.700	3.700	55.50	37000	27000
0.244	3.720	3.720	55.80	37200	27200
0.248	3.740	3.740	56.10	37400	27400
0.250	3.750	3.750	56.25	37500	27500

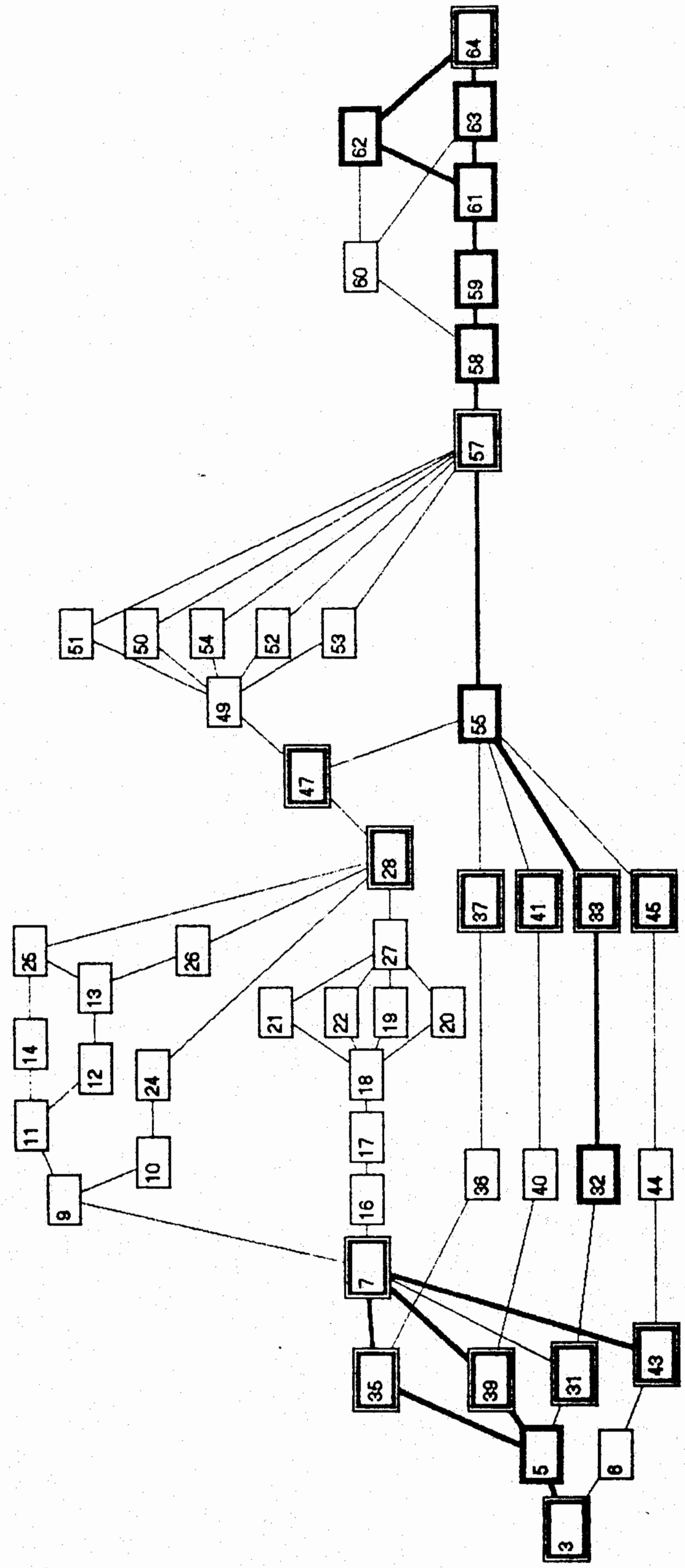
RESULTING IMPACT ON TASKS ON CRITICAL PATH

TASK 61					
DF (49)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$50,000	
0.000	1.000	1.00	12.00	50,000	$0
0.240	1.000	1.00	12.00	50,000	0
0.244	0.800	1.00	12.00	50,000	0
0.248	0.600	1.333	7.20	66,667	16667
0.250	0.500	1.500	6.00	75,000	25000
	CRASHED TO MINIMUM TIME				

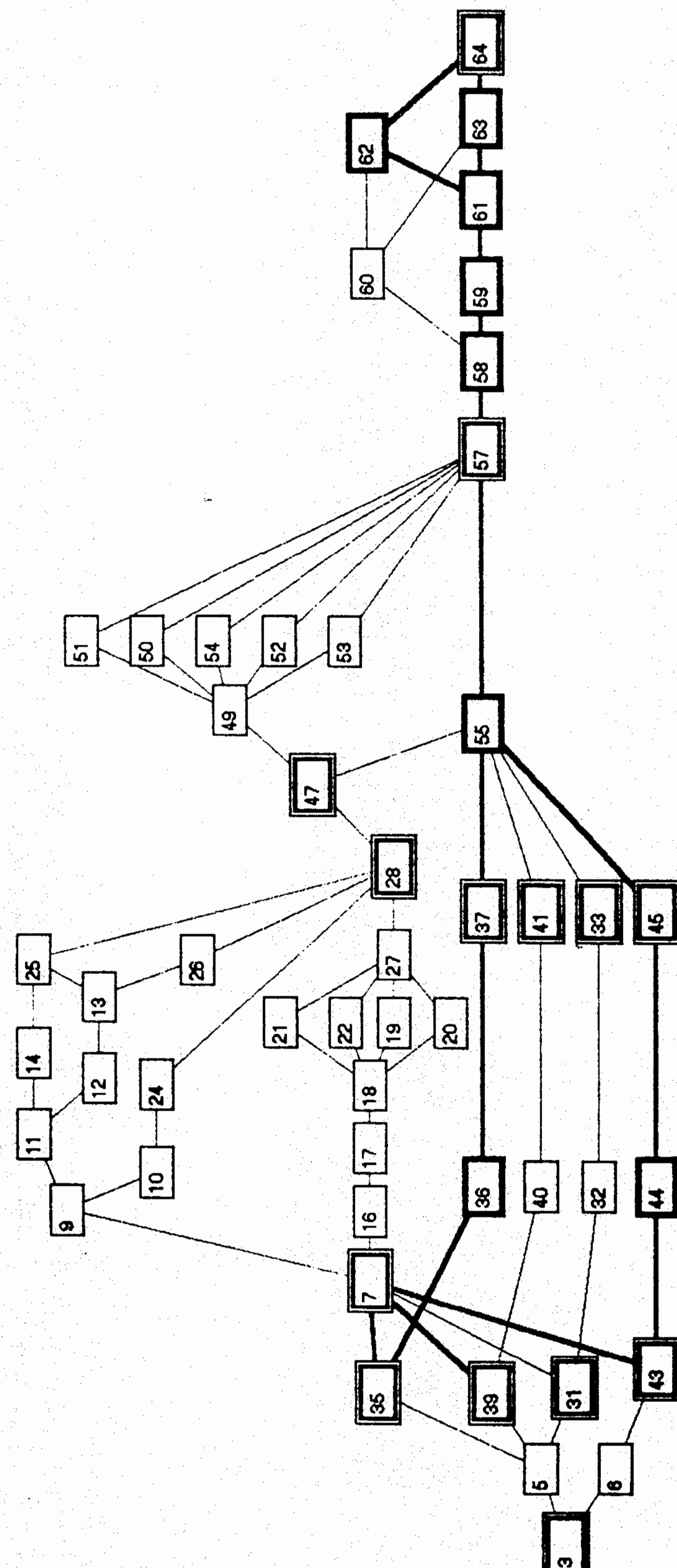
TASK 63					
DF (49)	TF	CF	O.A. TIME	O.A. COST	CHANGE
			12 HRS	$10,000	
0.000	1.000	1.00	12.00	$10,000	$0
0.240	1.000	1.00	12.00	10,000	0
0.244	0.800	1.00	12.00	10,000	0
0.248	0.600	1.333	7.20	13,333	3333
0.250	0.500	1.500	6.00	15,000	5000
	CRASHED TO MINIMUM TIME				

APPENDIX D. NETWORK DIAGRAMS

1. Network Dagram Showing Change Order on Task 32
(Dark Lines Denote Critical Path)



2. Network Dagram Showing Change Order on Task 36
(Dark Lines Denote Critical Path)



3. Network Diagram Showing Stoppage on Tasks 49 and 50
(Dark Lines Denote Critical Path)