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PETERSON BUILDERS, INC.

FEASIBILITY STUDY OF THE APPLICATION OF OPERATIONS RESEARCH METHODS TO SOLVE COMPLEX SHOP SCHEDULING PROBLEMS

FINAL REPORT

TASK ES-8-26

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EXECUTIVE SUMMARY

This project was performed by Peterson Builders, Inc. and the University of Wisconsin-Madison to determine the feasibility of solving complex shop scheduling difficulties with Operation Research (OR) techniques. The operations research approach begins by carefully observing and formulating the problem. The nature of the problem is then summarized in a model which is assumed to sufficiently represent the real situation. Any conclusions obtained from the model are therefore assumed to be valid for the real situation. This model is then modified and confirmed with appropriate experimentation.

A Ph.D. candidate from the University of Massachusetts was initially subcontracted to complete the OR model portion of the project. When he was unable to accomplish this a Ph.D. candidate and professor from the University of Wisconsin-Madison were subcontracted.

The laminating shop was chosen for this project because of its past problems with scheduling. The laminating process was very complex and contained many variables which made scheduling time consuming. The uniqueness of this shop was not fully understood by the two teams and therefore they were unable to simulate the shop with a computer model. The team from the University of Wisconsin-Madison produced a computer program but it was unable to schedule the shop.

Operations Research encompasses many areas from network techniques to statistics. Shipyards have used OR in the past to determine the most efficient method of pre-outfitting, statistically identify problem causes, etc. In this project the application of OR principles was difficult but this was due to the uniqueness of the shop chosen not the failure of OR. OR techniques have the potential for scheduling less complex shops. If this project had been performed on another shop, with less variables involved, the results would probably have been much different. Although this project did not yield the desired results many lessons were learned, one being that when attempting a project of this nature the variables should be controlled first. A scheduling model is contingent upon the variables being controlled.

While this project was in process, issues and problems were being addressed in the shop. These two procedures can't work concurrently. If the variables had been modified before the modeling was performed some of the uncertainty would have been removed and the difficulty of the project eased.

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INTRODUCTION

In this project Peterson Builders Inc. attempted to determine the feasibility of the application of Operations Research methods to solve complex shop scheduling problems. Specifically the purpose of the project was to determine the practicability and cost effectiveness of applying Operations Research (OR) techniques to solve complex scheduling problems in shops. Operations Research approaches problems with the scientific method. This process begins by carefully observing and formulating the problem and then constructing a scientific model which attempts to summarize the nature of the real problem. This model (usually mathematical) is assumed to sufficiently represent the real situation so that any conclusions obtained from the model are valid for the real situation. Experimentation then leads to modification and confirmation of the assumption.

Peterson Builders selected a department in the shipyard with many variables to consider in scheduling. They then selected a university as a subcontractor to construct a mathematical model with OR and simulation techniques. This model was to then be converted to a computer program which would simplify scheduling.

The department chosen for the project was the laminating shop. The lamination process was a complex one due to the many variables. This variability contributed to the fact that the shop was over budget, behind schedule, lacked job scope and had large work-in-process inventories. Because of these factors many hours were required to schedule shop operations. Besides saving the foreman a lot of time it was also hoped that this program would help to determine the shop's capacity and optimize use of the shop's resources.

The OR model portion of the project was initially subcontracted to a graduate student at the University of Massachusetts. He was unable to produce a working program so the project was reassigned to a Ph.D. candidate and a professor at the University of Wisconsin at Madison. They developed a program and made several revisions but they also were unable to create a program which could schedule the laminating shop's operations. Although the attempt at creating a computer program to schedule was unsuccessful, many valuable lessons have been learned from this project.

THE LAMINATION SHOP

Laminating, the process of gluing layers of boards together to produce a larger and/or stronger pieces of wood, is used at Peterson Builders to produce wood parts for the MCM (wooden hull ship) program. There are about 15,000 - 20,000 different laminates in each MCM and the present contract requires these laminates be produced within a two year period. They are grouped into fourteen product flow groups (see Figure 1) according to the type of wood used (white oak or douglas fir) and the size of the finished product. The size of the laminates range from 2" X 2" X 4" to 12" X 30" X 110'. The number of operations required in these product flow groups is from three to seven.

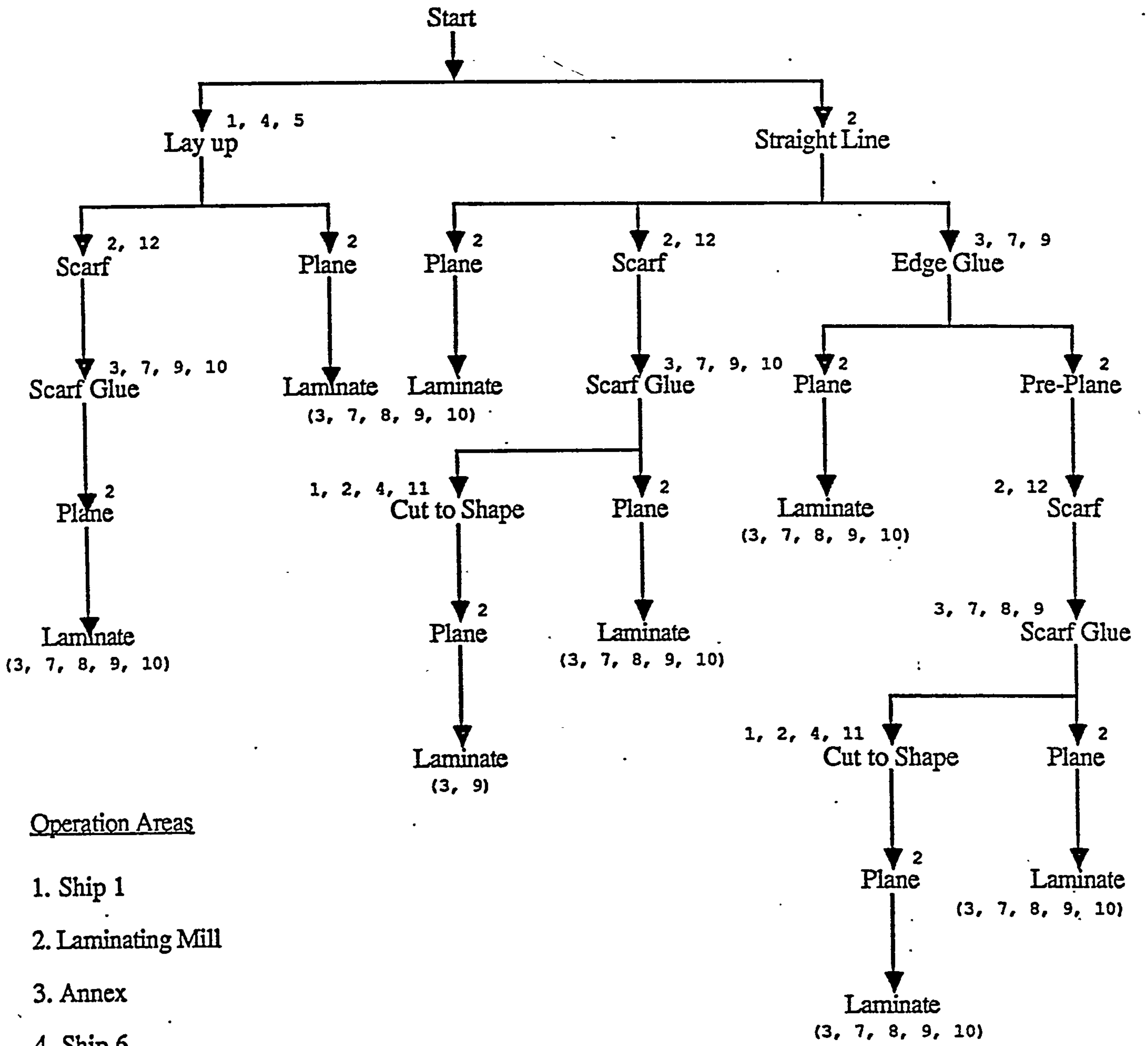
The laminating shop consists of four adjacent buildings which require outside material handling of parts between buildings. Figure 2 shows a layout of the buildings. There are ten different work stations and the number of men that can feasibly work at each station at one time are as follows:

WORKSTATION	# MEN
Rip saw	2
Cross cut saw	1-2
Cross cut with skill saw	1-2
Scarf Planer	1-3
Scarf gluing	1-4
Planer	2-6
Ship 1 jig	1-12
YP frame jig	1-6
MCM frame jig	1-8
Annex jig	1-10

There are usually 10-20 workers per shift and the laminating shop usually runs two 8-hour shifts per day, 5 days a week.

There are several factors which determine how much time operations will require. These include:

- the size and shape of the laminate,
    - For example, a twisted member and a straight



<u>Operation Areas</u>

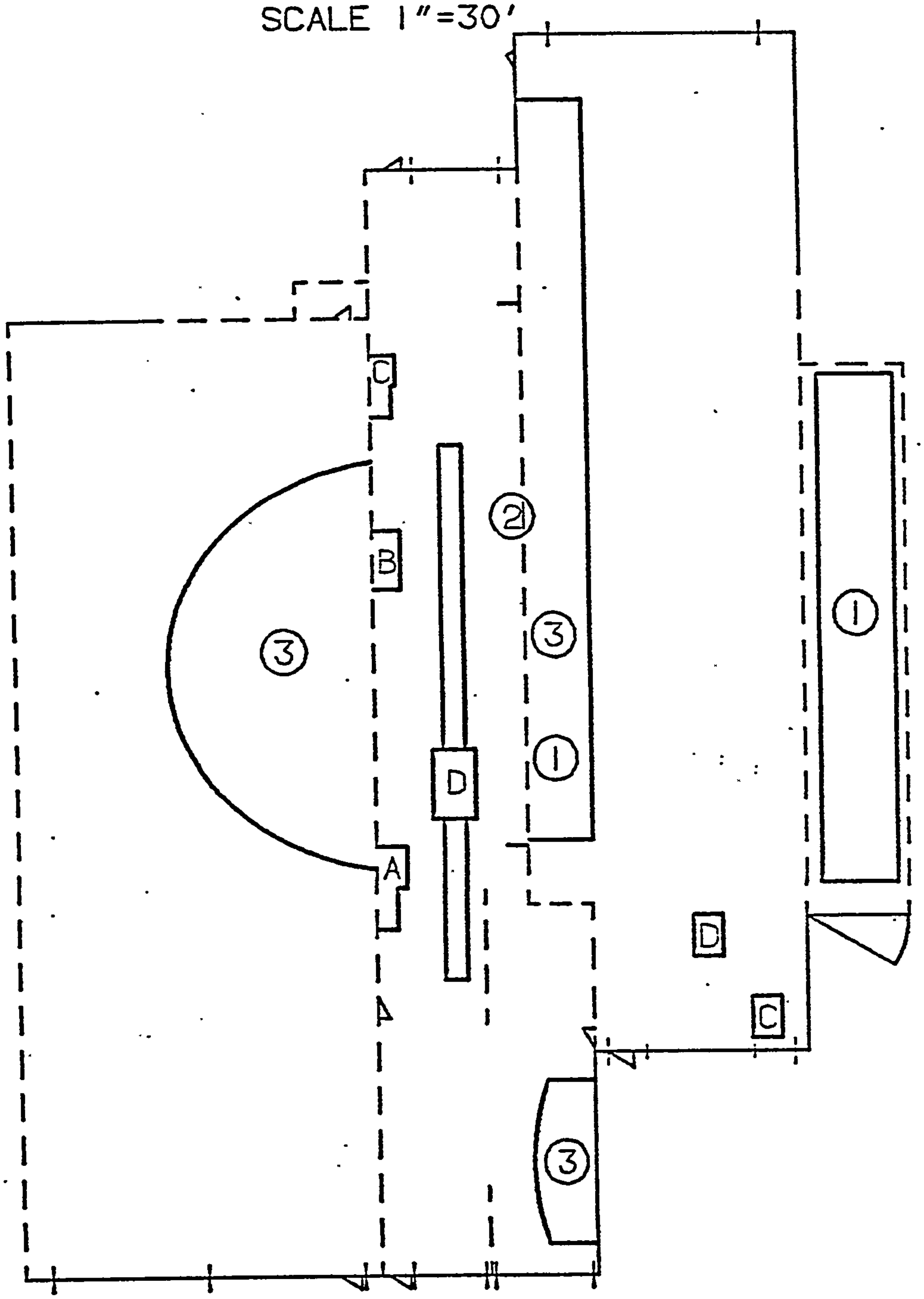
1. Ship 1
2. Laminating Mill
3. Annex
4. Ship 6
5. West Side
6. Ship 4
7. Jig 1
8. Jig 4
9. Jig 5
10. Jig 6
11. Outside
12. Building 7b

Figure 1. Product Flow Groups

PETERSON BUILDERS INC.

LAMINATING DEPARTMENT

SCALE 1"=30'



CUTTING OPERATIONS

- A. RIPPING
- B. CROSS-CUTTING
- C. SCARF-PLANING
- D. PLANING

GLUING OPERATIONS

- 1. EDGE-GLUING
- 2. SCARF-GLUING
- 3. LAMINATING

FIGURE 2 - LAMINATING SHOP

member of the same length will have similar operation times prior to laminating, but the twisted member will require a longer laminating time.

- A member with horizontal and vertical shape would have an increased laminating and scarf gluing time over a straight piece of the same size.

- A wide member (over 12 inches) will have a longer edge gluing time then a member under 12 inches.

* the quality of the raw lumber used for the laminate,

  - The quality of lumber directly affects the scrap loss of the wood. This scrap loss can vary from 30% to 60%, thus affecting the initial board footage required. This causes an increase in the sort, rip saw and edge glue times, therefore operation times may vary significantly for two identical laminates. This was one of the areas where the problem was identified and corrected by purchasing a better quality of wood.

* size of the lumber before it is processed,

* the personnel in the department with respect to both skill and availability,

  - Laminating personnel are cross trained to perform most jobs in the shop. This is necessary because, as stated previously, the number of men at most of the work stations varies greatly. This variation is caused by the fluctuation in individual laminate sizes being handled at each work center. The manning requirements might also change during an operation on a particular piece. During the gluing phase in the laminating of a 100' long piece, 12 men would be needed to carry the boards through the glue machine and to set the boards in place. The clamping phase of this operation however, would only require the use of six men.

* the weather,

  - The weather predominantly affects the material handling times of the products. Products and raw lumber must be pushed outside to be transported between the four buildings. If rainy conditions exist extra manhours must be spent to wrap and unwrap the wood to prevent it from getting wet. Snow and ice also increase the hours for material handling. The ambient temperature affects the working life of the glue during gluing operations. In hot weather more men will be put on a job to try to reduce working time with the glue. The ambient temperature also affects the core temperature of the wood. When the core temperature of the wood is cooler the laminate requires a longer pre-cooking time before it reaches the desired glue line temperature.

* restrictions,

- This includes curing requirements (i.e. white oak must be cured at 150 degrees for six hours and douglas fir must be cured for only two hours at 110 degrees),

- Gluing requirements (wood must be glued no longer then 24 hours after it has been planed),

- and others.

These are just a few of the major variables and details of the laminating shop. This information and much more detailed information was supplied to the subcontractors through a tour, phone conversations and letters as they worked on developing a scheduling program.

PROJECT HISTORY

After Peterson Builders submitted a proposal to conduct this Operations Research project and it was accepted, the development of the OR model was subcontracted to a graduate student at the University of Massachusetts at Amherst. The subcontractor stated that he was unable to create a program that would work because the number of bytes required by the program and the number of data entries required would be a binding factor on a PC. He also said that the variability in raw material, products and processing made it difficult. It was also felt that he did not understand the complexity of the shop because of the lack of time he spent at Peterson Builders.

Another source was sought and a Ph.D. candidate and a professor from the University of Wisconsin-Madison were subcontracted. They submitted a proposal in September 1986 in which they planned to complete the project in three phases. "Phase I was effectively a research phase which would allow them to determine whether or not it was going to be possible to build a feasibility checking system." Phase I was to be completed in three months and at the end of November 1986 the Madison team planned to meet with Peterson Builders and see whether or not their product had the potential to be a practical scheduling tool. "Phase II would take the crude research software of phase I and turn it into a usable commercial system by adding the necessary input and output software, "hardening" the computer code against inadvertent operator errors, developing a user's manual, etc."

After phase I was completed and the University of Wisconsin-Madison team visited Peterson Builders, many invalid assumptions or constraints were discovered in the program. Some of these were:

- No third shift capabilities were included.
- It did not back schedule from a given scheduling horizon.
- Additional manpower could not be added to this version
- No cut-to-shape or preplaning operations were allowed for.
- Jigs could only accommodate one job at a time.
- It did not allow a seven day work week.
- It did not allow more then eight hours for an operation.
- It was unable to schedule a period less than half an hour.
- and others.

They did not realize until this point in the study that more then one piece could be put in a jig at the same time. The Madison team planned to fix these rough spots and turn the program "into a usable commercial system" by January or February 1987. Yet when the program was revised and then revised again it was still burdened with constraints which contradicted the actual shop conditions.

SOFTWARE DEVELOPMENT

The team from the University of Wisconsin-Madison chose to write the computer code in Borland Turbo Pascal because of its speed and accuracy and they developed it for the IBM -XT/ATs. They decided to develop it from scratch instead of altering an existing piece of software because the only software available which could have been used was very expensive and one is not permitted to examine how the internals of the system function. The software Laminating Shop Scheduling Program (LASSP) is menu-based. Choosing certain items in the main menu will cause the program to drop one level in the "menu tree" (see figure 3).

LASSP basically has two modules, viz. a file management system (FMGR) module, and a scheduler module. The two modules communicate through the use of some common variables and some basic file access procedures. FMGR is used for the storage, retrieval and modification of frame and member schedules, and new member data. The scheduler module has as its input the frame schedules, existing member schedules, data for the current scheduling horizon, and a set of new members. Its output are schedules for new members which are added to the file of existing member schedules. The print option in the main menu can be used to either look at existing schedules/member data or to get a printout of the same in an easy to read format.

The amount of schedule/new member data to be entered could be large for a sufficiently long scheduling horizon; hence, LASSP has several features that allow it to correct mistakes. One of them is the ability to input

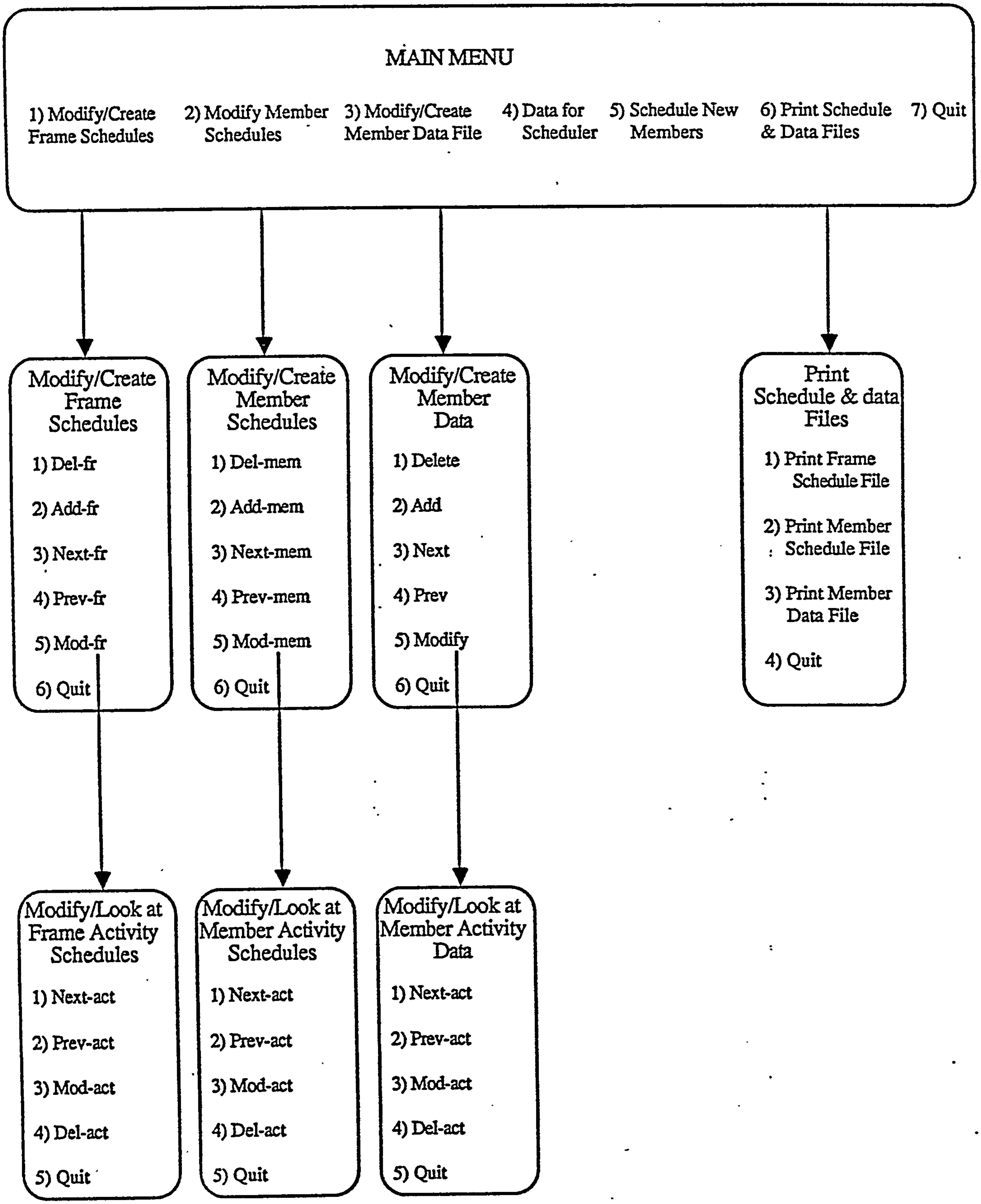


Figure 3. Menus in LASSP

a full screen of data. The user can get rid of any errors before exiting one screen and proceeding to the next. For corrections/changes at a later time, one would use the file management system.

The availability of workers and work centers was represented by "boolean arrays" indexed by the worker/work center number. Simple boolean logic operations such as "and" and "or" are used to identify free worker/work center time slots. The scheduling strategy is rule based. While certain rules are for enforcing precedence requirements, others have certain specific objectives. A rule which says that the final planing has to happen within 24 hours of gluing was designed to satisfy certain military specifications. Another rule which restricts the gap between any two operations of a member to a maximum of two shifts was included to reduce the in-process inventory. Another rule ensures that the gluing is immediately followed by clamping in the final lamination operation. The scheduler identifies a schedule (if one existed for the member) but not necessarily an optimal one.

FMGR stores information regarding frame schedules in two files; the same is the case with member schedules and new member data. In all cases, one of the files contains information about frames/members and the other has details (schedules/ data) of the various operations/activities for each frame/member. Each record of the file containing the member/frame information has the following fields, in addition to one or more fields that are needed for maintaining the file structure:

1. Member name,
2. Part number,
3.-8. Width and length required in jigs for edge gluing, scarf gluing and lamination (in feet),
9. Number of activities/operations required for the member, and
10. Due date.

For each new member data the individual records in the second file contain activity information including;

1. Activity/operation name,
2. Operations areas,
3. Number of workers required for this activity,
4. Amount of time needed (rounded to the next highest half hour).

In the case of frame/member schedules, the second file has fields containing the following information about scheduled activities:

1. Activity/operation name,
2. The operation area where this activity is scheduled to take place,
3. An array containing the identification numbers of the workers assigned,

4.-5. The day and shift this activity is scheduled for,

6. The time this activity is scheduled to begin, and
7. The time this activity is scheduled to end.

FMGR manipulates schedule and member data files using several file access procedures constructed using primitive file operations such as <u>read,</u> <u>write</u> and <u>seek.</u>

FMGR has procedures at two levels. The procedures at the lower level are basic file access routines for performing operations such as opening, closing and deleting files, and reading, writing, deleting and updating records. The procedures at the upper level are user routines and contain several calls to the lower level routines. These user routines are used for operations such as adding, modifying and deleting members from files, going to the next or previous member in the file, adding updating and deleting activity (operation) records, and going to the previous or next activity record of the member under consideration. The first four items in the main menu (see Figure 3) are for the FMGR module; choosing one of these would basically display a menu of user routines.

The two modules, FMGR and scheduler, interact through file access routines. The scheduler uses multidimensional boolean arrays indexed by workers or work centers, day and shift numbers, and hour in a shift to represent the availability of resources. These large boolean arrays are searched for an open slot in which the given operation will fit with a set of scheduler procedures. Another set of schedule procedures computes the earliest starting and latest finishing time.

After the first version of the program was completed Peterson Builders re-emphasized information which the University of Wisconsin team either did not understand or realize earlier, and adjustments were made to the scheduler. The scheduler assigned due dates by "back scheduling" (scheduling the last operation first and then proceeding backwards through the sequence of operations).

The program also had to be adjusted to accept more then one member in a jig at the same time. The jig cycle time would then have to be equal to the longest time of all the members in the jig. That made the jig fitting problem three-dimensional; the length and width of the area a piece requires and the cure time compose the three dimensions. This layout problem belongs to a class of operations research problems for which an optimal solution can not be obtained within a reasonable time frame.

Data structures which represented jig status and new member requests were added to the program as was a set of procedures for fitting members. These members are fit in on a FCFS basis. The first ones which will fit are placed in the jig.

The scheduler now uses two "passes" during the process of scheduling new members. The first or the initial pass comprises the following tasks. For each jig linked, lists of dummy jig cycles are created. Each jig cycle has zero load and unload times, zero load, and cure times equal to a contiguous chunk of holidays (includes weekends). The purpose is to force the cure times of jig cycles to happen during non-working hours in order to improve worker utilization. The frame and member schedules are then read in and the jig cycles updated. The objective while scheduling new members is to introduce new jig cycles without disturbing the schedule imposed on the jigs by the frames and members already scheduled. The list of new members is scanned and based on the due date and activity information the member is assigned to a jig for its final lamination operation. At this stage only the layout problem is addressed.

The actual scheduling occurs during the second pass. Only those members for which a jig was assigned in the initial pass are considered. For each of these members, the first task is to schedule workers for the various stages of the lamination operation (set up, glue, clamp, and removal from jig). If this task is successful then the program proceeds to schedule other activities required for the member. If a member has to be either edge or scarf glued then the jig layout and worker scheduling problems are addressed simultaneously. At the end of the second pass if there are any members that could not be scheduled the program advances the due dates of these members and again goes through the two passes.

ANALYSIS

At the termination of this project the computer program created by the University of Wisconsin still did not work correctly. They believed that given more time and money they would have been able to create a capable and useful scheduling tool. It was also felt that the basic reason the program did not work was due to the complexity of the laminating shop; there were just too many variables to be considered. The University of Wisconsin team obtained an output while in Madison, but when they went to Peterson Builders to demonstrate the program they weren't able to produce an output.

It is difficult to find good points in a program which doesn't yield an output. One positive aspect however, is that the laminating shop was able to identify and control some of the major variables identified during the research of the project. If the program did work its best value would probably be its ability to gross schedule a whole contract to determine manning and material requirements, but it would have little value as a day-to-day scheduler.

Bad points are not as difficult to discover. Of course the most obvious is that the program the University of Wisconsin-Madison team developed did not meet the needs of Peterson Builders. No one from Peterson Builders was able to get an output from the program. Another problem with the program was that inputting the necessary data was very time consuming. It required eight to twelve hours to input 28 days worth of production. For each member produced in the laminating shop each operation must be loaded and then for each operation the time, men, location and area in jig must also be input. As the shop foreman said, if all this information is known, why would one need a computer program to schedule it. If a mistake in inputting or a change in plans is discovered, everything must be input all over again. Because the schedules received from construction were not accurate, changes had to be made often. As a result of this even if the program worked it would not save the foreman any time.

The program seems to have strayed from the original objectives of providing a time saving tool for the scheduler which would optimize the shop's resources. In its current form the program could not be used as an optimizer; the foreman must do about 40% of the scheduling by hand and input the data into the program. The program then schedules the other members on a FCFS basis by taking the first members which will fit into the jig, without a thought of optimizing or finding a better fit. If entries are added the existing schedule wouldn't be altered.

Some of the problems in this project probably could have been avoided if the shop had been examined before the onset and if some improvements had been made. Since the start of the project some revisions have been made which have reduced some of the variations in the shop.

The scheduling is now much easier. A computer program which organizes the data is being utilized. This aids the foreman who is left to do the optimizing and the scheduling since he is the expert in this area.

Blocks of wood are now grouped according to dimensions and several blocks of similar size are produced together. Also some standards have been established within the shop. A better quality of wood is now ordered which helps reduce the time of required operations. The white oak is sorted before ripping and cross cutting to save time and the douglas fir, which does not need to be trimmed, is now being sorted according to length while it is still in the warehouse. This helps the scheduler know what material is available. A system for more efficient wood tracking has also been established which has led to a better flow of material.

After all of the changes were made the complexity of the lamination shop was greatly reduced and the need for the scheduling program virtually eliminated.

There are many other reasons for the lack of success in the project. Among these could be the lack of sufficient funds and other resources. Another very important reason was the lack of understanding. The University of Wisconsin-Madison team did not ask many of the right questions, considering the complexity of the lamination shop. They thought they understood the shop but obviously didn't because they imposed many constraints in the program which did not hold true in the shop. Communication problems may also have resulted from the distance between Peterson Builders and University of Wisconsin-Madison. Peterson Builders did suggest that someone from Madison come and observe the shop for a week or so and also offered to send two people to Madison for a short time. They either felt it was impossible or unnecessary and therefore they never gained a total understanding of the shop.

OR APPLICATION

Operations research is the scientific method of solving problems found in operating systems. There are many techniques available to accomplish this from network techniques to statistics. Statistical techniques include:

- linear programing: can be used for finding optimal production schedules, inventory policies, plant location and layout, and labor assignment policies.

- simulation: can be used to develop alternate solutions for preventative maintenance schedules, production planning and scheduling, inventory control, plant layout and capital equipment acquisition and replacement.

- forecasting
- regression analysis

At the time of this project the lamination shop was experiencing a lot of variability because of the wide range of products, the variability in times for operations and the uncertainty of future needs. All of this made it very difficult to apply operations research and try to optimize. If some of this uncertainty had not existed the application of OR may have been more feasible in this situation.

Because of the special conditions in the lamination shop the program written for it would be applicable to other shops only with modification. It would probably be much easier and more appropriate to apply this approach of OR technology to other job shops. OR does have potential in other circumstances which are less complex and more stable.

There are many opportunities in a shipyard where OR could successfully be applied. In scheduling it is best used for situations where the processes are more predictable. It could be applied in shops such as the machine shop, the pipe shop, plate fabrication and sheet metal. The team from Madison approached the situation with an OR solution which would probably fit these shops and others, but the lamination shop is unique and features many variables not found in average job shops.

Operations Research has been successfully used in shipyards many times in the past. In one example, a statistical application was used to objectively support evidence. Operations Research statistically identified and confirmed an assignable cause to cost overruns. This overruled the possibility that the cost overruns were just a chance happening.

This example was a rather non-traditional application of OR and it serves to show the unlimited potential that exists. Other techniques that have been used in the past include network analysis to analyze the problems of pre-outfitting. Network analysis was used to minimize the cost while maximizing the unit load by figuring which tasks should be included and when they should be done.

CONCLUSION

After two less than successful attempts, the hope of a computer program to do the scheduling was abandoned. Although this project did not yield a scheduler as was the original objective, Peterson Builders did learn from the research. This project has forced an examination of the lamination shop. As a result of analyzing the shop and its complexities many improvements have come about. A computer program is now being used which organizes the data and the optimizing is left to the expert, the foreman. Basically Peterson Builders learned that before attempting a project such as this the situation should first be examined in detail. Any problems found should then be solved to help simplify the project or eliminate its need. The variability of the processes, material, etc should have first been reduced in this project since a scheduling model is dependant upon the variables being controlled.

In this project the application of OR principles was very difficult, but this was due to the uniqueness of the situation not the inadequacy of OR.

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