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The Virtual Shipyard: A Simulation Model Of The Shipbuilding Process

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ABSTRACT

This paper describes a unique software program that simulates the dynamic complexities of the ship construction process. The program, called ShipBuild , was developed by Decision Dynamics, Inc. (DDI) under a Small Business Innovation Research (SBIR) contract sponsored by NAVSEA. The program greatly simplifies the planning and replanning process, making it easy to create a good production plan and keep it current. This simulation model of the shipyard production process captures both the essential physical shipbuilding activities and the essential management decision-making activities that support the physical production processes. The application consists of two independent submodels, a simulation capability and a results viewer component. The first submodel identifies the overall shipyard facility and manpower resources and the second identifies the construction tasks required to build a ship. The submodels interact to calculate the specific allocation of resources over time necessary to produce the ship.

The output generated from the program provides the durations and manhour loadings of elements of the ship construction process based upon dynamic resource availability. The output (unlike other scheduling programs for which durations are typically input and resource allocations an output) provides both schedule and resource use. Task durations are calculated based upon the manhour requirements, the number of people assigned and their productivity. Output generated by the application can assist Program Managers and Design Engineers in analyzing the manhour cost and schedule impacts of alternative designs and construction sequences. The program can also help to quantify the cost and schedule impact of delay and disruption as well as assist in identifying the most effective management actions to overcome such problems.

INTRODUCTION

Problem

Planning is the most critical and vexing problem in the shipbuilding process. To be successful, a strategic plan must integrate and manage the multitude of functions that are key to the construction process. Planners must learn how to minimize the impact that changes and delays have on plans and quantify their contribution to the total cost of a ship. What, for example, is the best construction sequence for a ship? How can engineers design a ship for the most affordable construction? How can a shipyard best utilize its resources during the construction process? How can the negative impacts of design changes and delays be minimized?

Designers and builders are continually challenged to find solutions to these complex questions. Yet answers to even the most difficult problems are eventually identified, plans are produced and the ship production process is begun. Unfortunately, the plans formulated to direct the project at the start are frequently upset by unexpected delays, unanticipated changes and unforeseen difficulties. Managers must decide how to reallocate resources to resolve each problem as it emerges. Revised plans are then needed to accommodate the myriad deviations from the original strategy. In severe cases of delay and disruption, managers must create new plans to replace versions no longer effective. However, creating and changing plans requires a tremendous amount of time and resources. Therefore, managers are often very reluctant to redo their plans unless things go terribly awry.

Solution

New management tools are being developed to help unravel complicated relationships and bring new understanding to the control of complex dynamic processes such as shipbuilding. This paper describes a unique, new software program that was developed to simplify the planning and replanning process. This application assists managers in creating a good plan and, more importantly, makes it easy for them to replan and to evaluate the effect of the revised plan.

This dynamic simulation of the ship construction process, captures the essential physical shipbuilding and management decision-making activities that support the production process. This is the first application of shipbuilding management theory embodied in a dynamic interactive simulation model. By capturing the complex set of feedback interrelationships that drive

dynamic behavior, the program is capable of quantifying manhour cost and schedule tradeoffs, tracking changes in productivity due to internal and external conditions, and replicating the disruption caused by delays and changes. The software consists of two independent submodels. The first identifies the overall shipyard facility and manpower resources and the second identifies the construction tasks required to build a ship. The submodels interact to calculate the specific allocation of resources over time necessary to produce the ship (Figure 1).

Key Features

Shipyard planners and managers can use the application to assist in analyzing the dynamic behavior of a sequence of related shipbuilding activities. The fabrication of components and the building, joining and outfitting of subassemblies, assemblies, blocks and zones are all types of activities that can be modeled in the program. Shipyard managers can simulate shipyard schedule changes and labor transfers in response to construction delays. These functions allow managers to accurately and quickly quantify the impact of
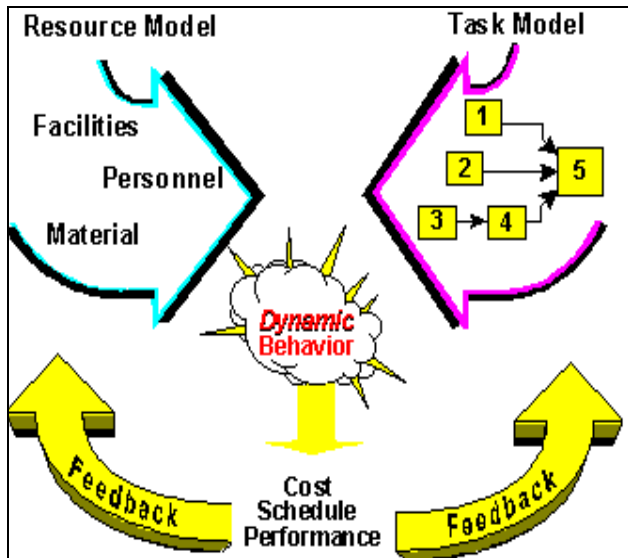

Figure 1. Model Operation

construction delays on manhour cost and schedule. The program tracks how the delays may trigger shifts in construction activity sequences, changes in schedule, and reassignment of the workforce among different tasks.

Feedback Structures

The simulation model offers three special advantages over conventional planning tools and traditional estimating models derived from statistical analysis of historical cost data. The first advantage is that real-world causal linkages between system elements are explicitly recognized and those links within the feedback structures that control system behavior are captured. Anyone examining the model can immediately understand both the logic of its organization and the meaning of its parameters. This

transparency is essential to model validation. The more intelligible the model, the easier it is for the user to verify its logic and to rely on it for decision support analysis.

Second, because the application replicates system interactions, it provides far deeper insights into dynamic behavior than those derived from traditional static or econometric models. This insight gives shipyard planners and managers an intuitive feel for why tradeoffs arise over time, when they threaten substantial risks, and how they can best be resolved. A better understanding of the dynamic behavior of the ship construction process leads to improved performance and reduced costs.

Third, planners and managers are able to develop sophisticated "what-if?" scenarios for testing and analysis. Alternative schedules, design changes, or assembly sequences can all be easily defined and tested. Such "what-if?" testing provides a much broader analysis of construction delays and manhour cost and schedule impacts than can ever be obtained from simple manipulation of databases. The program provides a quantifiable basis for measuring the outcome of alternative management actions and creates a framework for controlled experimentation. Simulation lays a scientific foundation for accelerated advances in shipbuilding management.

Ship Hierarchy

The task submodel functions are organized into four activity types: ship, block, work package, and task. The activities are structured in a hierarchy sequence from ship down to task; the ship being the highest level in the hierarchy. To define the ship construction, the user must layout the activities required to build the ship and select various elements associated with the activities.

The ship layout is composed of individual tasks that come together to create interim products, called work packages. Work packages, in turn, are assembled into blocks and blocks are erected to produce the ship (Figure 2). Work packages may also be identified by unit and/or zone. The elements in this hierarchy are further defined by sequence dependencies in which the fabrication or assembly of any element may depend upon the prior completion of one or more other elements. In practice, the ship task sequence follows normal PERT (Program Evaluation and Review Technique) diagramming conventions.
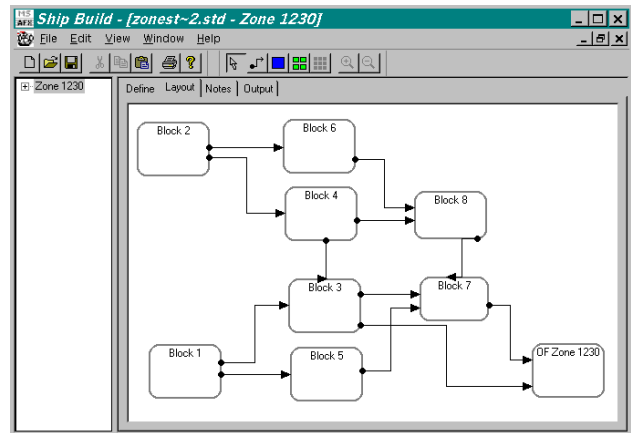

Figure 2. Ship Blocks Layout

Work Packages

Each work package is composed of one or more tasks which identify the work needed to create an interim product or to complete work at one construction site or stage. Interim products are defined not only by the tasks necessary to create them, but also by the following three additional variables:

- location (where the work is to be done),
- space (footprint size), and
- weight.

All three variables can be separately identified in the program.

Tasks

Each work package may include as many individual tasks (usually trade-related) as required to create the interim product. ShipBuild ™ is capable of simulating the effect of all of the many thousands of individual tasks that are involved in building a ship. These tasks describe the efforts necessary to create the many interim products which are developed during different stages of construction. Subassemblies (tasks) are joined to create assemblies (work packages), which are developed into blocks. Blocks are then erected and outfitted to produce the ship. These activities may be further defined by identifying sequence dependencies between one or more other elements in the hierarchy.

At the lowest level, only four variables define each task:

- work backlog (scheduled manhours to complete),
- labor resources (trade skills) needed to accomplish the work,
- equipment needed to accomplish the work, and
- dependencies (relationships to other tasks).

Shipyard Resources

The data from the shipyard submodel is used during simulation to dynamically assign resources to the work tasks to complete ship construction. The yard contains a labor force (identified by skill and trade) plus any number of work stations (identified by work type).

To define the shipyard layout, the user must identify the work stations in the yard by work type and the labor force by skill and trade. The shipyard submodel contains a facilities area where the main yard work stations and associated data are located (Figure 3). After defining the work stations in the shipyard, the user can specify elements associated with the work stations including:

- work type;
- equipment requirements and baseline productivity;
- days work stations are scheduled for activity; and
- lift, space and productivity associated with work stations.

At the yard level the user can also select policies that determine management responses to schedule pressure. The user may also define productivity losses due to such conditions as overmanning, overtime or lack of skills.
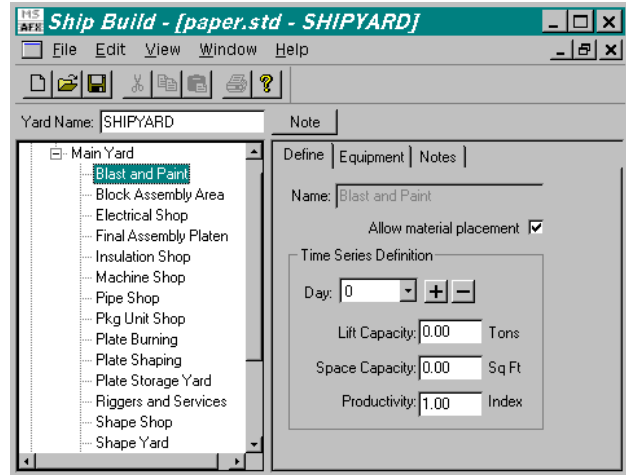

Figure 3. Shipyard Work Stations

The shipyard submodel also defines the labor resources of the yard (Figure 4), including:

- number of personnel (by trade and skill),
- number of shifts,
- baseline productivity of various shifts,
- time to hire, and
- baseline productivity of various trades.

The user can also define the labor items for each trade, and the separate skill levels for any trade.

Once defined, the shipyard facility and manpower resources can be altered to create new simulation results. Shipyard resources do not need to remain constant. Different yard configurations and facilities can be set up to test how changes during work will affect schedule and manning. For example, aged equipment or facilities may be phased out and replaced by modern, more efficient equipment or facilities during a simulation in order to assess how disruptions in process may affect production.
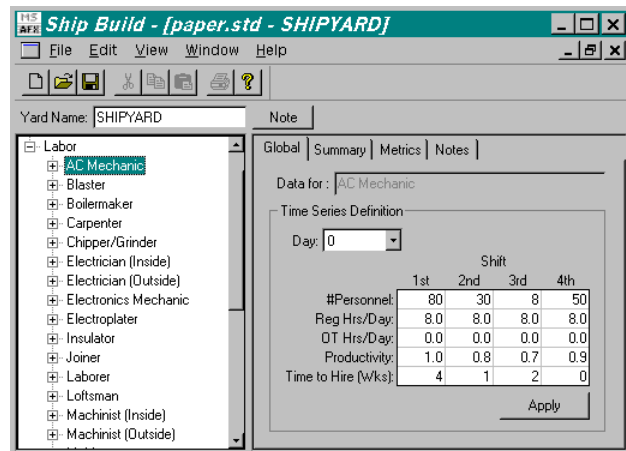

Figure 4. Shipyard Labor Resources

Default Data

The program supplies a default list of labor trades and work stations. The user can enter the total number of individuals assigned to each trade and each skill level within a trade at any time during the shipbuilding process. These numbers are applied to various tasks as appropriate during simulation runs. Unless the user has entered new data, the model is always ready to run using the default data. Default data values aid model development because the user can always check the impact of any data entries during model development.

Productivity

Unlike many other planning tools, the program incorporates a variable productivity function. Productivity is a function of an expected baseline productivity that is modified by such factors as learning, overmanning, skill mix, overtime and work sequence. The application generates these factors internally during simulation in response to changing shipyard conditions. For example, if a delay results in a period of overtime work, productivity for the overtime hours may be less than productivity depicted in the normal baseline.

Alternatively, if a task is late, overmanning may be necessary in order to regain schedule. The result of manning a task beyond the most efficient level is a reduction of productivity. It will take more actual manhours than planned to accomplish the work.

The software, uniquely, provides managers with the ability to assign the actual number of people to a job in order to accomplish it within the scheduled period of time as productivity per person decreases. Lower productivity values can also be assigned to work accomplished on second and third shifts, weekends or overtime.

Schedule Pressure

Another unique feature of this application is the ability to automatically calculate the need to assign more than the desired number of people to a task if, during a "what-if?" simulation, a task falls behind the baseline schedule date for that task. "Schedule pressure" is a non-dimensional multiplier applied to the desired number of people for a task (as established for the task in the ship construction submodel) to increase the number of people, or the amount of overtime needed to accomplish the task on schedule. If the number of people assigned exceeds the maximum number of people that can be efficiently applied to a task, then the productivity loss function will come into play. The program will then calculate how many budgeted manhours of work will be accomplished each day for the actual manhours expended.

Task Matching

During simulation, the computer regularly recalculates task needs and priorities. Task needs and resource availability are updated for every hour of every day until the construction process is completed. Task priority, a function of sequence, critical path and schedule pressure, determines access to resources. Tasks may only be accomplished at open work stations that specialize in the type of work requested. A blasting and painting task, for example, could only be accomplished at a blast and paint station. Some welding, assembly and equipment installation tasks, however, may be accomplished at a number of different work stations.

When a resource match is made, the task begins. While the task work is being performed, the resources utilized by the task are not available to any other task. In some cases, however, tasks with very high priorities may interrupt work in progress on non-critical tasks to gain quicker access to resources.

The multiple calculations for task matching and work accomplishment happen very quickly. In a matter of minutes, all of the thousands of tasks required to build a ship can be simulated.

Operation

During simulation, the model continually updates its internal schedules, computing new critical paths and tracking progress on all tasks and work packages. Output views of both Gantt charts and manning curves, are always available to the user.

Once a preferred baseline plan has been determined, the model may then be used to quantify the impact of design changes and delays on schedule and manning. By altering task definitions and work package sequences, changes can be simulated and compared to the baseline plan. Similarly, introducing delays by holding up various tasks will cause the model to seek "work around" solutions, causing out-of-sequence activities and even creating future rework requirements. Comparison of results to a baseline will show the difference in time and labor between two alternative scenarios.

When unexpected changes do occur during ship construction, planners often find it difficult to quickly replan activities and alter work sequences. The program offers a rapid method for replanning the entire production process or only a selected portion of the process. Replanning can be performed as often as desired and only requires that the change be identified in the model by appropriate changes to tasks and work packages.

Whenever a change or a delay causes the simulation to deviate from the planned baseline, tasks that are delayed begin to generate schedule pressure. As schedule pressure rises, it can trigger a variety of management actions. (These actions are dependent upon user-controlled settings.) For example, schedule pressure may translate into overmanning due to shifting labor among work stations. Alternatively, schedule pressure can be ignored in order to forecast what would happen without management intervention.

Output

The software provides program managers with the ability to successfully develop a strategic plan by integrating and managing the multitude of functions that are key to the construction process. The results achieved and the output available from simulation runs include:

- schedules for all tasks and for all interim products;
- overall ship schedule;
- labor manning (by shift and by trade);
- labor hours for all tasks, work packages, blocks; and
- total labor hours for the ship.

Thus the program will automatically transform a list of task manhour budgets and a list of yard resources into a schedule and manning forecast. Furthermore, the program will do it over and over again, in just minutes, helping planners discover the optimal task layout and the most efficient allocation of shipyard resources.

APPLICATIONS

To demonstrate the application of ShipBuild™ to a realistic shipbuilding situation, the construction of eight blocks in one zone of a ship was modeled. All stages of construction and manning estimates for each of the eight blocks were developed from historical data. Several different scenarios of the construction process were then evaluated, to demonstrate how the type of information generated by the program can assist design engineers and managers in the shipyard.

The eight blocks and their dependencies make up the center hull section of a cargo vessel. Blocks 1 and 5 are adjoining Starboard Side Blocks; 2 and 6 are Port Side Blocks. Blocks 3 and 4 are starboard and port deck blocks, respectively, inboard of 1 and 2, and 7 and 8 are inboard of 5 and 6.

Using the capabilities within the program, the blocks and the connecting arrows depicting sequence dependencies, were quickly developed (Figure 2). Similarly, the dependencies of the various work packages that create each interim product were identified and drawn (Figure 5) as were the tasks within each work package. After creating the logic diagrams, the details of each task were added, including total manhours budgeted for the task as well as labor resource requirements.

Next, the dependencies among tasks were defined (Figure 6). The prior tasks can be those within the same work package or any task in another prior work package. This is another important area in which this software differs from most conventional scheduling programs. Instead of using lag as a specific duration in days or weeks, lag is entered as a percentage of the preceding task's duration (since the preceding task duration is yet to be determined by the simulation run). The default relationship is "finish to start" with no predefined lag.

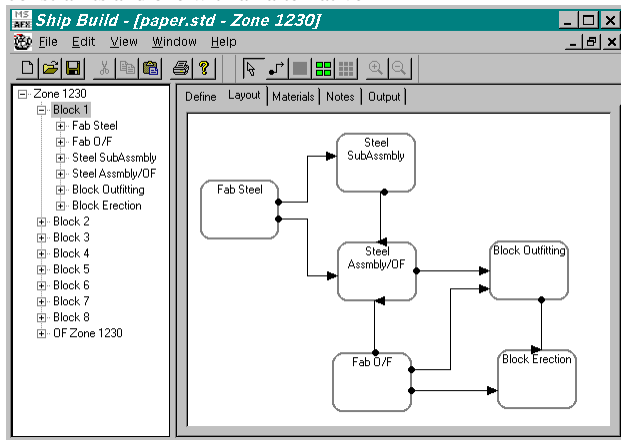Two model applications are presented: one with manpower constraints and one with an alternative

Figure 5. Work Package Layout

construction sequence.

Scenario One - Manning Constraints

In the first scenario, several different manning constraint policies were simulated to define the impact that the constraints would have upon the overall time and manhour expenditures for completing the work.
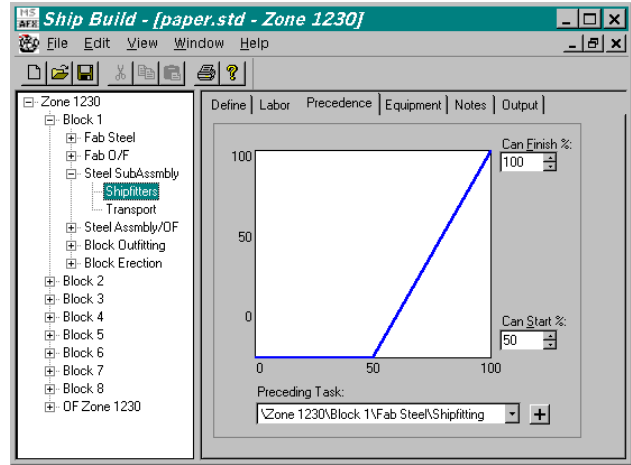
Figure 6. Defining Task Precedence

Figure 7 is a graphical display of three alternative situations. The baseline plot shows the planned cumulative manning curve for the project. The second curve shows the effect of a lack of personnel available at the start of the program. The total manhours remain the same, but the schedule is delayed. The third curve shows the effect of applying additional manhours, but at a lower productivity (due to overmanning) to complete the job on time.

The baseline plot (depicted by the blue line) displays the total number of planned manhours over the length of the project; approximately 340 days. The green line displays an increase in the number of planned project days resulting from a decrease in available labor. The red line curve describes an even greater increase in planned project days caused by overmanning with an associated lower productivity level.

The scenario in Figure 7, demonstrates the schedule and manning impacts of delay and disruption resulting from any interruption of the work process.
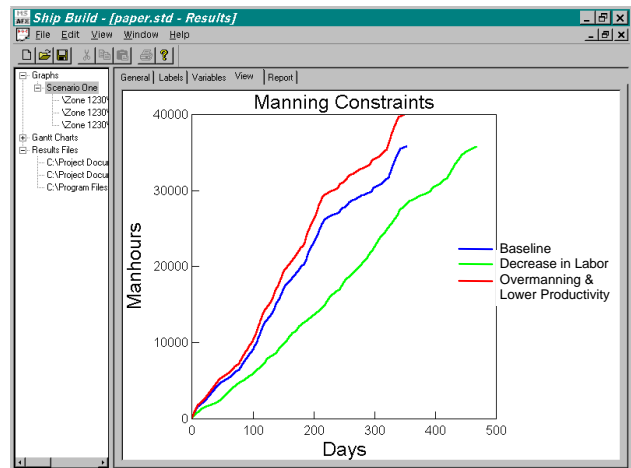
Figure 7. Manning Constraints

The unique capability of the program is best demonstrated by this type of scenario because the loss of productivity due to overmanning work packages or work tasks is taken into account in the simulation. The resultant additional cost in total manhours and/or the resultant additional time delay due to manpower

limitations can be described in tabular format, graphical format and Gantt charts.

Scenario Two - Construction Sequence Alterations

In the second scenario, a different block erection sequence simulation was compared to the baseline block erection sequence. The two simulations were compared to determine whether there were advantages from a manning or schedule duration standpoint for different construction approaches.

In Figure 8 the blue line again displays the baseline plot simulated in the first scenario. The curve depicted
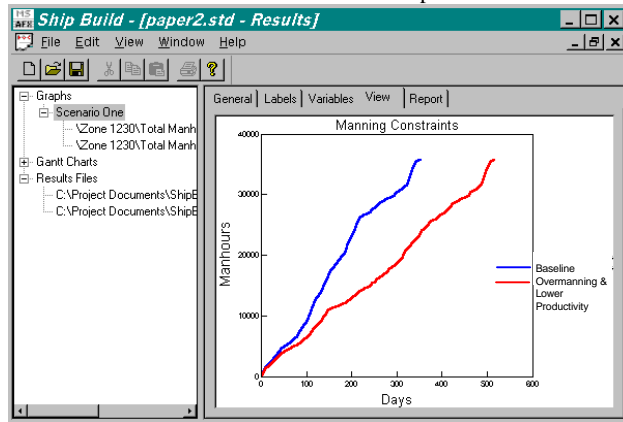

Figure 8. Comparison of Construction Sequences

by the red line in this scenario, describes a change in the block construction sequence. In the baseline simulation the blocks were constructed simultaneously. For example, blocks one, three, five and seven were simulated as one construction process and blocks two, four, six and eight as one process (Figure 2). In the second simulation, the blocks were developed sequentially with one followed by two, two by three, until all eight blocks were constructed. The red line curve indicates an increase in the number of project days required to complete the alternative construction erection sequence.

Results

The result of applying the simulation model to quantify real and potential delays and to identify alternative management actions to ameliorate those delays has the potential to save shipbuilders millions of dollars. Use of the software can produce a measurable reduction in both schedule and design change costs.

It should be clear from the model description, that this application can be used to explore not only real changes and events but also "what-if?" assumptions. By defining a series of "what-if?" scenarios, a model user can compare the relative impact of many different variables on system behavior. For example, alternative ship designs, task sequences, shipyard resources, problem areas and management responses can all be tested in a search for the best solution. Quantifying alternative "what-if?" scenarios also provides a very effective risk analysis tool. The model structure captures the complex set of feedback interrelationships that drive dynamic behavior. Thus the model can quantify manhour cost and schedule tradeoffs, track changes in productivity due to internal and external conditions, and replicate the disruption caused by delays and changes to the work.

Benefits

The ShipBuild™ model introduces a new generation of management and planning tools that can be used to complement or supplant current CPM (Critical Path Method) and PERT methods. The model runs on a PC (Personal computer) and has the power to track an extensive number of variables. This power translates directly into a more realistic representation of the shipbuilding process and therefore a more useful management tool. The software offers shipyards throughout the country the potential to gain a competitive edge in managing complex projects.

Use of the program will assist design engineers and shipyard planners in three important ways by increasing planning flexibility, control over work sequence, and confidence in the plan.

- Greater flexibility allows planners and managers to plan early, often and more effectively. Users can evolve plans that best address anticipated ship and yard conditions and quickly and efficiently replan whenever necessary.

- Providing planners with greater control over work sequence, task activities and resource allocation, ensures that the most important work gets done first and that manhour cost and schedule tradeoffs are clearly assessed.

- Use of the software provides planners with greater assurance that the plans are correct, that manhour cost and schedule can be safely predicted and that risks are reduced to a minimum.