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Developing Scheduling Systems for Daewoo Shipbuilding: DAS Project

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Abstract: Daewoo Shipbuilding Company, one of the largest shipbuilders in the world, had difficulties with planning and scheduling its production process. To solve the problems, Korea Advanced Institute of Science and Technology (KAIST) and Daewoo have been jointly performing the DAS (DAewoo Shipbuilding Scheduling) Project for three years from 1991 to 1993. To develop the integrated scheduling systems, several technological breakthroughs were necessary such as hierarchical architecture between systems, constraint directed graph search, spatial scheduling, dynamic assembly line scheduling, and neural network based man-hours estimation. Besides these technological research issues, we adopted the phased development strategy, which consists of three phases of vision revelation, data dependent realization, and prospective enhancement. The DAS systems were successfully launched in January 1994 and are being actively used as indispensable systems in the shipyard resulting in a significant improvement in productivity and reengineering of the scheduling process.

Keywords: Scheduling, Manufacturing Industries, Artificial Intelligence, Shipbuilding.

1. Introduction

Daewoo Shipbuilding Company is one of the largest shipbuilders in the world, employing over 12,000 workers and posting $2 billion in sales in 1993. The main products are VLCC (Very Large Crude Oil Carrier) and container ship. Its shipyard has three docks. One of the docks is the largest in the world capable of manufacturing one million ton VLCC and has a Goliath crane which can hold up to 900 tons. Shipbuilding is a make-to-order manufacturing and takes about 18 months to complete. Since the manufacturing process from the time of orders to the final delivery is very complicated, the scheduling and control of human, material resources and facilities is a very complex task and a nightmare. Since its establishment, the company has struggled to develop an effective scheduling to achieve total optimization. Poor scheduling keeps workers waiting for the prerequisite sub-assemblies, causes fluctuation of work loads resulting in expensive overtime work, and may cause delay in delivery. The company has attempted various project management software such as PROJACS, VISION, and X-PERT, as well as in-house development with conventional programs; but all these efforts failed because they could not grasp the whole picture of complicated interrelated scheduling activities. The other reason is that no software could support the dynamic spatial layout even though the spatial resources with material handling equipment like cranes are bottlenecked resources.

To develop the integrated scheduling systems to overcome these problems, KAIST and Daewoo have jointly performed the DAS (DAewoo Shipbuilding Scheduling Expert Systems) Project for three years from 1991 to 1993.

The DAS systems were successfully launched in January 1994 and have been indispensable systems in the shipyard, resulting in the significant improvement in productivity and reporting the visible and positive impacts in several ways. The DAS project adopted various Operational Research and Artificial Intelligence technologies to cope with the scheduling task. The key sub-systems in DAS project are as follow:

DAS-ERECT: Erection Scheduler at Docks

DAS-CURVE: Curved Block Assembly Shop Scheduler

DAS-PANEL: Panelled Block Assembly Shop Scheduler

DAS-MH: Neural Network based Man-hour Estimator

The key approaches that have contributed to the success of DAS project can be characterized as follow:

1) Hierarchical Architecture for the Shipbuilding Scheduling

2) Constraint Directed Graph Search

3) Spatial Scheduling

4) Dynamic Assembly Line Scheduling

5) Neural Network Based Man-hours Estimation

6) Three-phased Development Strategy

To explain the whole project emphasizing the key technological issues, the remaining sections review these issues one by one. The explanations about the implementation and maintenance, technology transfer, and organizational impact are followed.

2. Hierarchical Architecture between Scheduling Systems

The first approach that we have taken to handle the scheduling complexity is the hierarchical architecture as many complex tasks do. A large tanker is divided into hundreds of sized blocks as shown in Figure 1. The blocks can be categorized into two types: flat-bottomed, which are assembled in the Panelled Block Assembly Shop (PBS), and curved-bottomed, which are assembled in the Curved Block Assembly Shop(CBS). Multiple blocks may be assembled into larger ones (called super-blocks) in the Pre-Erection Shop to reduce the assembly time needed at the main erection docks. At the main docks a number of blocks and super-blocks are constructed ('erected') using a very large Goliath crane. In a shipbuilding plant, there are usually pre-erection shops next to the dry docks as shown in Figure 2.

[FIGURE 1. APPEARS HERE]

Figure 1. A Ship and its Partition into Blocks

For the erection scheduling at the dock, the system DAS-ERECT employs the hierarchical scheduling architecture along with the constraint directed graph search technique that would be explained in the next section. During the generative scheduling stage, DAS-ERECT considers only the aggregate capacities of lower level assembly shops like PBS and CBS. Then DAS-ERECT requests the relevant lower level schedulers to deliver the blocks by the due dates as shown in Figure 3. The scheduler at PBS and CBS -- DAS-PANEL and DAS-CURVE, respectively -- schedules its own work area according to the requested due dates as well as the detailed spatial and manpower constraints. When a certain block cannot be assembled in time, the scheduler reports the trouble to the higher level dock scheduler to obtain assistance in resolving the inconsistency. Then a negotiation starts between shops by adjusting the overtime level or due date of the block. Currently, a computerized Group Scheduling Support environment is under construction as a second phase of DAS project. Another advantage of hierarchical scheduling is the robustness during the reactive scheduling phase (Lee, Suh, and Fox 1993).

[FIGURE 2. APPEARS HERE]

Figure 2. Typical Shipbuilding Procedure

[FIGURE 3. APPEARS HERE]

Figure 3. Hierarchical Architecture of Shipbuilding Scheduling

3. Constraint Directed Graph Search in Erection Scheduling

A bottlenecked technology for the erection scheduling at dock was its search technology. PERT (Program Evaluation and Review Technique) technique is not appropriate here because the capacity constraints cannot be considered.

The important characteristics of erection scheduling can be summarized as follow:

1) Sequential Erection at Each Dock: Blocks and super-blocks in each dock have to be erected one at a time because there is only one Goliath crane at each dock.

2) Large Search Space: Since the schedulers have to consider multiple ships, each composed of 400 ~ 500 blocks, a manual search for the best schedule is beyond mental processing capacity.

3) Technical Knowledge for Erection Sequencing: The technical knowledge which restricts the erection sequences should be taken into consideration.

4) Utilization of Resources: Key resources in shipbuilding comprise human workforces, cranes and space. To utilize these resources effectively, a schedule should be established to balance the loads among PBS, CBS, Pre-erection shops and docks.

The objectives and constraints of erection scheduling can be summarized as follows.

− Objectives

- Balanced loads among different stages of assembly operations

- Minimization of makespan

− Constraints

- Resource Constraints:

1) Human resource capacity denoted as Man-Hour (MH)

2) Crane capacity

3) Area capacity of workplates

- Technical Constraints

Ten types of technical constraints are grouped into three classes. Examples from each class are as follow:

1) *General Technical Constraints*: A keel laying block should be selected among the non-side and bottom blocks of engine-room or mid-body part.

2) *Constraints on Partial Sequence*: All the blocks should satisfy the structural stability condition. Therefore the transverse sequence of the mid-body must satisfy the following sequence: Bottom →Bulk-Head →Side-Shell → Deck.

3) *Constraints on Precedence Relationship*: The block that needs supporting facilities must be erected after having erected the base blocks on which the facilities should stand.

To handle this problem, the constraint directed graph search technique is adopted. The first observation is that a node in graph search can correspond to a block as shown in Figure 4 and Figure 5. The graph search expands nodes, and selects a proper node possibly using an evaluation function (Nilsson, 1980). However, the application of a pure graph search is not appropriate in this case because measurement of multiple realistic evaluation functions is almost impossible. The second observation is that there are precedence constraints between nodes due to the technical constraints. To accommodate the graph expansion framework with the constraints consideration, we amalgamated an algorithm called *Constraint Directed Graph Search (CDGS)* (Lee et al. 1995b).

To develop an algorithm for the Constraint Directed Graph Search procedure, let's consider the case of a single vessel. This algorithm can be extended to multiple vessel and multiple dock cases. For the detail algorithm for Constraint Directed Graph Search for shipbuilding, refer to Lee, Choi, Yang and Kim (1994).

Notations

WHOLE: all nodes

PATH: list of scheduled nodes

POTENTIAL: union of adjacent nodes to the ones in current *PATH* excluding those in the *PATH* itself

ERECTABLE: list of nodes that satisfy the technical constraints among the nodes in the current *POTENTIAL*

Constraint Directed Graph Search Algorithm

Phase 1: Initialization

1. Acquire the required data and constraints.

2. Put all the nodes to be erected in the *WHOLE list.*

Phase 2: Selection of Keel Laying Block

3. Generate the candidate keel laying blocks. In this step, utilize the potential keel-laying block selection constraints.

4. Select a keel-laying block based on the selection strategy. Put the selected keel laying block in the *PATH list.*

Phase 3: Graph Expansion

5. Expand *POTENTIAL* of current *PATH* by adding adjacent nodes while not in the *PATH*.

6. If the *POTENTIAL* = ϕ and *WHOLE* = ϕ, all nodes are erected appropriately. Stop.
If *POTENTIAL* = ϕ while *WHOLE* $\neq \phi$, the search procedure has problems. Stop with an error message.

7. Among the nodes in *POTENTIAL*, select the nodes which also satisfy the technical constraints.

8. If *ERECTABLE* = ϕ, backtrack.
Then, go to Step 5.

9. If *ERECTABLE* $\neq \phi$, select the best node to be erected from *ERECTABLE*. Update each list.
Go to Step 5.

For explanatory purpose, suppose three erected blocks PA, PB, and PC whose path is *PATH* = { PA, PB, PC }. For those blocks, there are ten potentially erectable blocks *POTENTIAL* = {P1, P2, ... , P10} as shown in Figure 4 and Figure 5. We can derive *ERECTABLE* list from the *POTENTIAL* list by considering technical constraints such as *structural stability*. By applying this constraint, suppose the *ERECTABLE* list has reduced to {P1, P2}. To select one block from *ERECTABLE*, we evaluate blocks P1 and P2 using two criteria: load level at lower-level assembly shops and the earliest erection start time at dock. Suppose P2 is selected, then the *PATH* list becomes {PA, PB, PC, P2}. The above procedure is repeated possibly with some backtracks until all blocks are erected. The Figure 6 shows an erection network scheduled by DAS-ERECT.

[FIGURE 4. APPEARS HERE]

Figure 4. Spatial Position of Potentially Erectable Blocks

[FIGURE 5. APPEARS HERE]

Figure 5. Partially Expanded Graph Search

[FIGURE 6. APPEARS HERE]

Figure 6. Erection Network Scheduled by DAS-ERECT

The knowledge base used in the CDGS is composed of object-oriented data and constraints. Objects represent the hierarchical structure of blocks and super-blocks, shop, relative position, estimated duration and man-hours, and generated schedules.

4. Spatial Scheduling in Shipbuilding

4.1. Introduction

In the shipbuilding plants which handle the heavy and bulky blocks, it is necessary to employ expensive material handling equipment like cranes and work plates. Since the space equipped with such facilities is usually limited and bottlenecked, the scheduling needs to consider the spatial resources as well as traditional ones like manpower and machines. We call this kind of scheduling a *spatial scheduling* in this project. As the term implies, the spatial scheduling deals with the optimal dynamic spatial layout schedules. In a shipyard, spatial scheduling problems occur frequently in various working areas like erection docks, pre-erection shops, and block-assembly shops, etc. So far, the spatial scheduling has been carried out manually without any automated aids. Even though human experts have much experience in spatial scheduling, it takes long time and heavy efforts to produce a satisfactory schedule because of its huge search space required to consider blocks' geometric shapes. Since spatial scheduling for six months is beyond the scope of human mental capacity, it has been impossible to build such a large scale spatial schedule in advance. Therefore, automation of the spatial scheduling process has been a critical issue for the improvement of productivity in the shipbuilding plants and the total integration of scheduling systems.

In Daewoo, there have been some prior attempts to solve the spatial scheduling. One approach was a simple spatial scheduling system approximating the shape of blocks to rectangles. But the field schedulers rejected using it because the approximation sacrifices the spatial utilization too much. So in our research, the system DAS-CURVE approximates the blocks' shape to polygons as users agreed. Another failed attempt is the interactive spatial scheduling support system that helps human schedulers by providing them the graphic user interface. The interactive system was not effective because it could not automate the tedious spatial scheduling process and reduce the information burden and scheduling time. It only replaces the paper and pencil with the computerized interface.

The objectives of spatial scheduling may vary somewhat, depending on the nature of a given plant. In general, however, spatial scheduling systems pursue due-date satisfaction, maximal utilization of spatial and non-spatial resources, and minimization of waiting time for work-in-process and final product inventories. Typical constraints include crane capacity, man-hour availability, assembly due date, precedence between associated assemblies, physical adjacency of coupled objects for operational efficiency, minimum required distance between blocks, and maximum acceptable waiting time for completed and work-in-process blocks. Typical necessary input data include jobs with due-dates and their constituent activities, two-dimensional geometric spatial objects of the activities, required processing time for each activity, and spatial shapes of work plates.

In the shipbuilding domain, the shapes of most objects tend to be convex polygons like triangles, rectangles, or trapezoids. Some blocks may have some local concavity. However, in most cases, the local concave space is not usable by other objects. Therefore, they can be approximated as convex polygons. In shipbuilding, the orientation of an object is prefixed to four alternative orientations (0^o, 90^o, 180^o, and 270^o) to ensure stable crane operations.

4.2. Search Space in Spatial Scheduling

To find the feasible positions of an object a_i within a workplate *W* that do not overlap a scheduled object b_j, we can adopt the notion of configuration space (Lozano-Perez 1983; Zhu and Latombe 1991). Configuration space is the space through which the reference point of an object (a robot, for example) with fixed orientation can possibly pass without colliding with present obstacles. In our research, there are two kinds of configuration spaces: *Obstacle Avoiding Space* and *Inner Locatable Space*. The *Obstacle Avoiding Space* $S(a_i|B)$ is a space where the reference point of an object a_i can be located without colliding with the already located objects B = $\{b_1,...,b_n\}$ which are regarded as obstacles. *Inner Locatable Space* $S(a_i|W)$ is the space where the reference point of an object a_i can be located within the boundary of a work area *W*. Thus the *Feasible Locatable Space* $S(a_i|B,W)$ can be derived by intersecting the above two spaces: $S(a_i|B, W) = S(a_i|B) \cap S(a_i|W)$. The *Feasible Locatable Space* can be computed using the Polygon Setsum algorithm (Lozano-Perez 1983) which computes the setsum of two convex polygons.

Figure 7 illustrates the spaces where the object a_1 is to be located within *W*, on which two objects b_1 and b_2 are already located. Since the Feasible Locatable Space is continuous, it is impossible to find all the points in it. To extract a set of meaningful discrete points out of the continuous space, we define *Distinctive Locatable Point Set* $D(a_i|B,W)$, which consists of the vertices of the Feasible Locatable Space. The *Distinctive Locatable Point Set* can be computed using the 'Point-in-Polygon' algorithm (Preparata and Shamos 1985) to determine whether a point is in a convex polygon and the Polygon-Intersection algorithm (O'Rourke etc. 1982) to compute the intersection of two convex polygons.

Theoretically speaking, the Distinctive Locatable Point Set does not guarantee finding an optimal location (Lee and Lee 1995). However, the points have empirically provided very satisfactory locations with the advantage of computational efficiency.

[FIGURE 7. APPEARS HERE]

Figure 7. Feasible Locatable Space and Distinctive Locatable Points

4.3. Search in the Distinctive Locatable Point Set

Since most of layout problems are NP-complete, we propose four positioning strategies which can be effectively applied contingent to the situation:

1) *Maximal Remnant Space Utilization Strategy* intends to fully utilize the fractured space by choosing a position which can maximize the intersectional space between the block to be located and the union of orthogonally circumscribed parallelepipeds of already located blocks. This strategy is effective in pairing nonrectangular activities.

2) *Maximal Free Rectangular Space Strategy* is based on the idea that a layout with a larger remaining rectangular free space can accommodate larger blocks later. This strategy takes a more global perspective than the first strategy because the parallelepipeds of free space for this strategy contains a global information on the status of spatial layout,

while the *Maximal Free Rectangular Space Strategy* needs only the local information at the vicinities of located blocks.

3) *Initial Positioning Strategy* attempts to find the best location among the near corner points of a work plate. To find such a point, this strategy chooses a point which can minimize the maximal distance between the vertices of a new block and a corresponding corner point of the work plate.

4) *Edging Strategy* can be effectively applied when a new block has to be placed adjacent to the edge of work plate. The strategy can be realized by selecting a position which can minimize the sum of distances of vertices of the block from the edge of the work plate.

Since each strategy has its own merits depending on the situation, we synthesize a composite positioning algorithm which can apply an adequate positioning strategy, contingently. Key issues in composite positioning are the identification of situation, reduction of search space, and selection of effective strategy. In this study, we identify four types of situations depending on the existence of already-located objects, the attempted location (near corner, edge, or other object), and the shapes of the objects. The strategies are by no means complete. However, we have empirically verified that these situation types can still quite effectively capture the possible situations. For the detailed description about the strategies, refer to Lee, Lee, and Choi (1996).

4.4. Backtracking and Adjustment in Spatial Scheduling

If we cannot find a feasible schedule for a certain day, we have to backtrack to adjust the current spatial layout, the starting times of already-scheduled activities, and/or the resource commitment level (overtime level in shipbuilding). Some of the backtracked adjustment could have been avoided if we could have looked ahead what is needed to be located over the next several days. However, obtaining information about the precise impact of these future objects is almost as expensive as the scheduling itself. Therefore, we adopt the backtracking and adjustment strategy.

For the shipbuilding domain, we utilized the following six types of adjustment:

1) Work Plate Re-Selection

2) Intra-Plate Spatial Adjustment

3) Inter-Plate Spatial Adjustment

4) Intra-Plate Temporal Adjustment

5) Intra-Plate Spatiotemporal Adjustment

6) Inter-Plate Spatiotemporal Adjustment

For the details about the adjustment strategies, refer to Lee, Lee, and Choi (1996).

4. 5. Shops with the Spatial Scheduling Systems

DAS-CURVE is a representative spatial scheduling system (Lee and Lee 1992; Lee, Lee and Choi 1994) developed for the curved-bottomed block assembly shop. The system generates the spatial schedule of assembling blocks meeting the due-dates imposed by DAS-ERECT. The block assembly shop has about 15 work plates with 8 cranes to lift blocks and sub-assemblies. The resources are limited by the availability of the spatial work plates, as well as the non-spatial resources of manpower and cranes. Figure 8 illustrates an output screen of DAS-CURVE showing a snapshot spatial layout status of the eight work plates in the shop for a day (93/03/19 which means March 19, 1993). Eight rectangles labeled as 2bay-1, 2bay-2, 2bay-3, ..., 3bay-5 are the workplates, and the polygons in each rectangle are the two-dimensional shape of the blocks scheduled to be assembled on the workplate at the specified date. Figure 9 illustrates the dynamic spatial layout of a work plate (3bay-1) during an indicated time interval from 93/01/20 (Jan 20, 1993) to 93/04/10 (April 10, 1993). By using DAS-CURVE, the spatial utilization ratio could exceed the target of 70 percent by 5 percent.

As the term 'spatial' scheduling implies, the visual interactive scheduling is an essential feature for the scheduler's initiative. Therefore, DAS-CURVE is equipped with the mouse-based graphic user interface. To maintain consistency between the user's visual interactive input and the invisible constraints, the reactive scheduling capability works behind the screen, usually adopting the adjustment methods described earlier. The spatial scheduling system is also used in the pre-erection shops and erection shops.

[FIGURE 8. APPEARS HERE]

Figure 8. Output Screen Showing a Snapshot of Spatial Layout in DAS-CURVE

[FIGURE 9. APPEARS HERE]

Figure 9. Output Screen Showing a Dynamic Spatial Layout of a Work Plate in DAS-CURVE

5. DAS-PANEL: Panelled Block Assembly Shop Scheduler

Another important issue in shipbuilding is the development of a scheduling system for the panelled block assembly shop, DAS-PANEL (Hong, Kim and Lee 1993), in which blocks and their sub-assemblies are welded on the assembly lines and adjacent off-lines, respectively (Figure 10). Since the block size and compositions of sub-assemblies are diverse, the scheduling should encompass the detailed scheduling of sub-assemblies as well as the main assembly line scheduling of blocks. DAS-PANEL has two characteristics: (1) Since the blocks made in the shop are one-of-a-kind, the speed of the assembly line should not be fixed in advance. To improve the productivity of the assembly line, it is necessary to generate a schedule which can dynamically change the cycle time according to the characteristics of blocks. (2) Its objective is to minimize not only the assembling time of blocks on the main line, but also the waiting time of sub-assemblies and blocks. DAS-PANEL was built using a typical forward chaining rule-based tool UNIK-FWD written in C. Figure 11 shows dynamically changing cycle time generated by DAS-PANEL.

[FIGURE 10. APPEARS HERE]

Figure 10. The Paneled Block Assembly Shop with Assembly Line and Off-lines.

[FIGURE 11. APPEARS HERE]

Figure 11. Output Screen Showing Dynamically Changing Cycle Time in DAS-PANEL

6. Neural Network based Man-hours Estimator: DAS-MH

To establish reliable scheduling systems, the estimation of accurate man-hour requirement for each assembly is a prerequisite. To supply the required welding man-hours inputs of each one-of-a-kind block for DAS scheduling systems, we adopted the artificial neural network as an estimator (Lee and Kim 1994).

To build a reliable and efficient neural network model, we take the following research procedure.

1) Select candidate input variables: Four categories of variables are selected with possible values for each variable.

2) Eliminate unnecessary variables: Highly correlated redundant cardinal variables are filtered out by stepwise regression as a preprocessor.

3) Train and test the network with and without the preprocessing.

4) Compare the estimation performance by the neural network with the one by the regression analysis.

First of all, we have selected 4 categories of variables that influence the welding time. They are candidate input variables of the neural network model.

1) Ship Type

Usage: Select one of the following values.

VLCC(Very Large Crude oil Carrier)
OBO(Ore Bulk Carrier)
COT(Crude Oil Tanker)
B/C(Bulk Carrier)
CONT(Container)
P/C(Product Carrier)

Dead Weight (which means the weight that the ship can carry)

2) Block Type

Locus: Select one of the following values.

Side-Shell
Bulbus-Low
Engine-Room-Side-Upper
Fore-Deck
Longitudinal-Bulk-Head
Transverse-Bulk-Head
Transverse-Non-Corrugated-Bulk-Head
Mid-Ship-Bottom

Panelled or Curved Bottom

Single or Double Shell

3) Block's Physical Characteristics

Welding Length

Joint Length

Block's Weight

4) Shop Type

Assembly Shop: Select one of the following values.

3DS(Three Dimensional Shop)
BOS(Building Outfitting Shop)
PBS(Panelled Block Shop)
A-7(Area Code No.7)

Indoor or Outdoor for each shop

In total, we have 10 italicized candidate input variables: 4 cardinal and 6 nominal scale variables.

To eliminate unnecessary variables, we have adopted the stepwise regression approach with four cardinal variables: dead weight, welding length, joint length, and block's weight.

We expected that the drop off multicollinear variables keeps the model robust. In this manner, the joint length and block's weight are finally selected. Thus, 8 variables are eventually selected as the inputs to the neural network. Figure 12 shows a configuration of the neural network developed using a neural network developer, UNIK-NEURO (Lee et al. 1994).

To confirm whether the neural network model significantly outperforms other possible approaches, we have compared with two approaches: multiple regression model and simple regression through origin. We compare with the simple regression through origin because this method has been used in the field for years with the name "Unit Estimator". To estimate by the unit estimation method, the joint length of the block is used as an independent variable for each group of blocks which are grouped into 17 families. According to the experiment, the neural network model significantly outperforms the multiple regression and the simple regression through origin as seen in Table 1 (Lee and Kim 1994). Measure of errors adopted for evaluation is defined as follows.

$$Error(\%) = | (MH_e - MH_a)/MH_a| * 100$$

where Error(%): estimation error percentage,

MH_e: estimated man-hours, and

MH_a: actual man-hours.

Approaches	Neural Network	Multiple Regression	Unit Estimation
Average Error Standard	12.1%	13.6%	15.4%

Deviation of Error	9.7%	12.2%	11.7%
Maximum Error	43.0%	75.0%	66.0%
Minimum Error	0.04%	0.004%	0.008%

Table 1. Errors by Each Approach

[FIGURE 12. APPEARS HERE]

Figure 12. Neural Network Configuration for Man-hour Estimation

7. Three Phased Development Strategy

For the implementation of an innovative and method-seeking project like DAS project, it is not always clear whether the data for the new system will be available with the justifiable cost-benefit. So we have adopted a three phased development strategy (Lee 1993) as summarized in Table 2: 1) Vision Revelation Phase, 2) Data Dependent Realization Phase, and 3) Prospective Enhancement Phase. This strategy can be contrasted with the conventional approaches (System Development Life Cycle, Prototyping, and Mixed Approach) which does not consider the data availability explicitly (Naumann and Jenkins 1982; Alavi 1984; Burns and Dennis 1985). In this phased approach, we considered not only user requirement but also data availability. The first phase was *vision revelation*. In this phase, the KAIST team has persuaded Daewoo that the DAS project is not a mere system development, but needs a theoretical research on the following issues that are explained earlier.

1) Constraint-directed graph search for erection scheduling considering the work loads at the preceding indoor shops

2) Spatial scheduling

3) Line balancing with flexible process planning and dynamic cycle time

4) Processing time estimation using neural network

5) Interface and coordination among multiple expert systems and databases

These issues were explored during the first year, 1991 regardless the availability of data, and prototypes of the DAS systems were developed using the tool UNIK, which had been implemented in LISP. These prototypes could successfully demonstrate the vision, although they could not provide the satisfactory speed.

The second phase was *data dependent realization*. Daewoo people were frustrated because they could not provide data necessary to run the prototype systems. However, it was a good checking point of identifying which data were available and which were not. This process required a close communication with the design division, because the initial prototype requires the information about the design specification from the CAD tools to automate the process planning and man-hour estimation. However, these data could not be provided until the current CAD system is upgraded to solid modeler which was not technically and economically feasible at that time. The other data which could not be supported were the erection sequence dependent man-hour and the processing time requirements.

Therefore, considering the data availability, the design of prototype systems was degraded. However, the management was delighted because the systems could run based on the currently available data although they were not ideal. The systems in the second stage were developed using C version of UNIK to enhance operational speeds. The systems were installed in the fields in 1992 and took tests under the real world situation.

The third phase was *prospective enhancement*. During this stage, the systems developed in the second stage were incrementally enhanced as the prototyping approach does. However, a difference is that the enhancement was oriented toward the target set at the end of the first stage. The systems will be gradually improved as the data become more available. The major source of data enhancement is attributable to the CAD system. In the final stage, we expect the concurrent engineering realized linking the design tightly with the manufacturing (Schwab, Schilli and Zinser 1993; Rosenblatt and Watson 1991).

Development Phase	Vision Revelation	Data Dependent Realization	Prospective Enhancement
year	First year '91	Second year '92	Third year '93
DAS-ERECT	Research on Constraint Directed Graph Search	Spatial Scheduling in Pre-erection Shop, System Implementation, GUI Implementation	Experiments, GUI Development, System Upgrade & Maintenance
DAS-CURVE	Research on Spatial Scheduling	System Implementation GUI Implementation	
DAS-PANEL	Research on Line Balancing with Dynamic Cycle Time	Rule base & Inference Engine Construction, System & GUI Implementation	
DAS-MH	Tool (UNIK-Neuro) Development	Neural Network Modeling & System Development	Experiment & Model Selection
Implementation Language & Tool	LISP Version Prototype	Operational System (C Conversion)	Installed in the field

Table 2. Development Process

8. Implementation and Maintenance

For this project, we have used the frame-based expert systems tool UNIK('UNIfied Knowledge') which is developed by KAIST and upgraded from initial LISP version to C version. Since we own the source codes and can improve them, it was a very adequate tool for this kind of project which requires flexible adjustment. UNIK has the features such as forward chaining (UNIK-FWD), backward chaining (UNIK-BWD), inductive learning (UNIK-INDUCE), rule generation from diagrammatic representation (UNIK-RuleGen), and neural network learning (UNIK-NEURO) and library of LISP-like functions(UNIK-Kernel). UNIK has the versions operating on UNIX , DOS, and MS-Windows. DAS systems were implemented on Sun SPARC station 10 series.

The systems are maintained by the programmers and knowledge engineers of Daewoo who were trained during this project. The schedulers are allowed to set the contingent scheduling strategy by setting the parameters for constraint base and rule base. To allow flexible system maintenance according to the change of plant layout and facilities, KAIST and Daewoo are currently conducting a research on the contingent scheduling system generator as the second stage of DAS, which is named DAS-II.

9. Technology Transfer

The DAS project team consisted of the Daewoo people and the KAIST people (Table 3). It was effective to send the three Daewoo people to KAIST for the closer joint research and development overcoming the geographic distance (about 500 km) between two sites. We observed that the roles of the project members evolved according to the development phases as Table 3.

Although key research issues are dealt with by KAIST team, the three Daewoo delegates who stayed in KAIST for three years have deeply involved in the system development. The role of these delegates was critical. During the project, they were liason between the KAIST technical team and the field experts. After the project, they returned to the plant and have become the leaders of maintaining and enhancing the scheduling systems as well as training associated colleagues in MIS and production scheduling division.

	First year '91	Second year '92	Third year '93	Roles
KAIST Research Team	9 persons	9 persons	6 persons	Research & Development Technology Transfer
	Research & Prototype Development, Knowledge Engineering	Inference Engine Development, Tool & System Conversion (LISP => C)	Advanced Implementation & Experiment	
Delegates - Daewoo	3 persons	3 persons	5 persons	3 years residence in KAIST
	Requirement Specification, Transfer, Learning & Training	Rule Base & GUI Development	Maintenance and GUI Development	
Management Team in Daewoo		4 persons	4 persons	Coordination, On the Job Training
		Project Management	Data Support & Training	
Domain Experts		11 persons	17 persons	In-house Training, Practice & Testing Support of Scheduling Masters
		Knowledge Transfer, Feedback, and Prototype Testing	Usage Learning and System Testing	

Table 3. The Number of Members in Each Group and Their Changing Roles

10. Organizational Impacts and Innovations

The impact of implementing DAS systems has been remarkable, although it is not easy to measure the benefits quantitatively. Innovations by using DAS can be summarized as follow.

1) Reduction of Scheduling Time

The networked scheduling systems in hierarchical architecture enabled the production management department to plan and control the plants totally reducing the negotiation efforts among plants. In the past, the scheduling took 10 to 15 days for a quarterly plan. Six or seven planners were always kept busy in preparing a single plan by the due date. They had no time to revise the first schedule at all. Now, the plan can be prepared through many simulations within 4 days with the DAS systems by less than 5 planners.

2) Selection of the Best Schedule from Simulation

The speed-up of the schedule generation time enabled the field schedulers to try multiple scheduling strategies and select the best schedule among the simulation results. In the past, it had been mostly impossible to determine whether a plan was appropriate before using DAS systems, but now it has become possible to confirm the appropriateness of the plan by comparing the multiple plans generated by the system.

3) Looking Ahead and Load Balancing

In the past, we could look ahead at most 3 to 6 months. Now, we can foresee up to 18 to 24 months ahead with DAS. So we become to know the time to control the load in personnel, equipment and work flow, which was not possible in the past.

4) Reengineered Planning Processes

Before using the spatial scheduling systems such as DAS-CURVE, the spatial allocation plan was made after the temporal allocation planning. Now, the integration of the two scheduling processes saves much time and efforts, and enhanced the quality of schedule.

5) Visual production management and control by graphical output

The graphical output screens generated from the systems like DAS-CURVE improved the planning and work productivity via clear communication between the management and workers.

6) Technology transfer from university to industry

DAS project is famous in Korea for its success in cooperating between university and industry. Now Daewoo has gained the ability of developing expert systems by herself.

7) Development Cost and Estimate of Payoff

The development costs for the three-year project was approximately $159,000 for the hardware and $675,000 for the research and development of both organizations. The total cost was approximately $834,000. Though the revenue implication for the project is not easy to calculate, the company estimated it based on the expected contributing rate to the production productivity and planning productivity improvement rate. Since the estimated contribution rate of DAS to the yearly production productivity improvement (15 percent) is 30 percent, and 50 percent to the planning productivity improvement respectively, the expected annual benefit by DAS project is about $4,000,000 which can far exceed the costs in the long run. The annual benefit is calculated by the following formula.

Contribution to the production productivity

= Total labor per year * Wage Rate * Productivity improvement * Contribution rate

= 6,000,000 (MH/year) * 12.5($/MH) * 0.15 * 0.3 = $3,375,000

Contribution to the planning productivity

= Planning manpower * Total manhour per man per year * Wage Rate * Productivity improvement

= 50 (person) * 2000 (MH/year-person) * 12.5($/MH) * 0.5 = $625,000

11. Conclusions

According to this experience of developing large scale scheduling systems, the key ingredients of the system are managerial insight on scheduling activities and effective heuristics, research capability on constraint-directed graph search and spatial scheduling, acquaintance with the frame and rule based expert system development environment, integration with optimization model, neural network based man-hours estimator, data requirement guiding but data-dependent phased development strategy, and effective technology transfer mechanism. It was really the mixture of operations management, Artificial Intelligence and Expert Systems, Operational Research, information technology, and organizational learning.

This experience tells us a lot about the gaps between academic communities: OR and AI should better understand each other for mutual benefit to solve complex real world problems (Lee 1990; Lee 1996; Lee and Song 1995).

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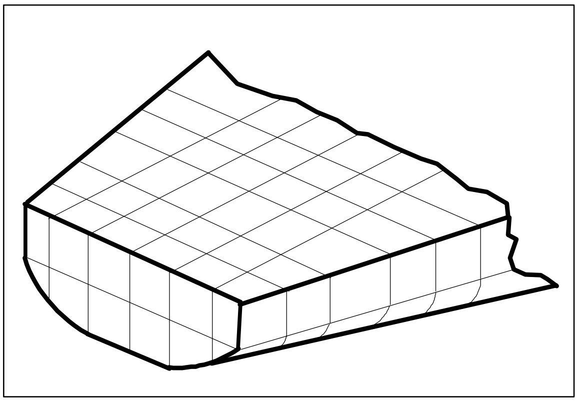

Figure 1. A Ship and its Partition into Blocks

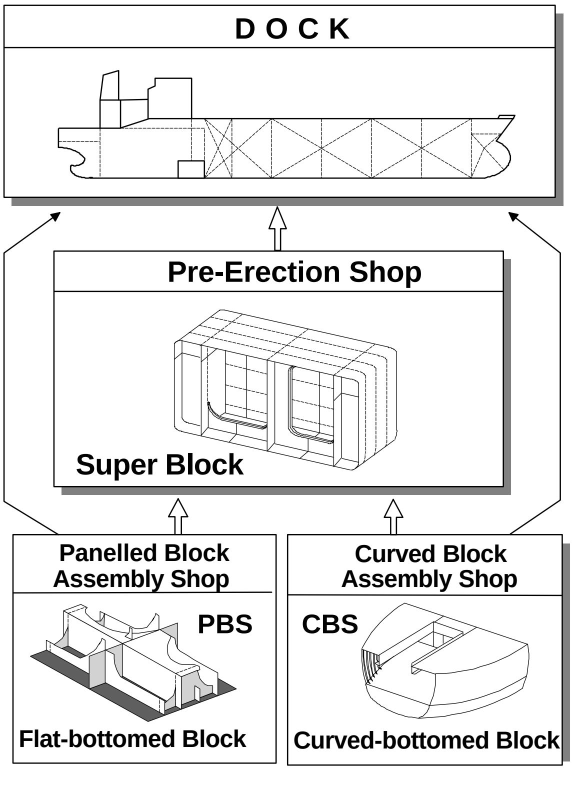

Figure 2. Typical Shipbuilding Procedure

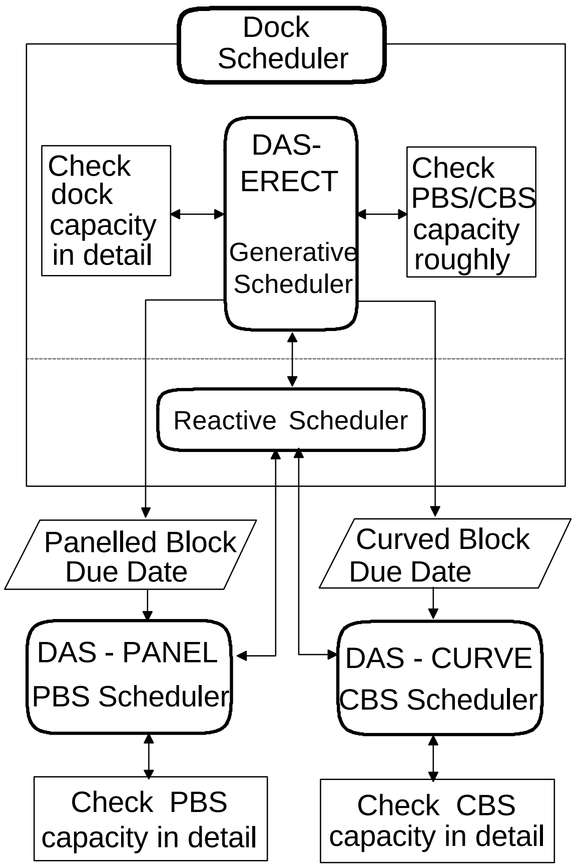

Figure 3. Hierarchical Architecture of Shipbuilding Scheduling

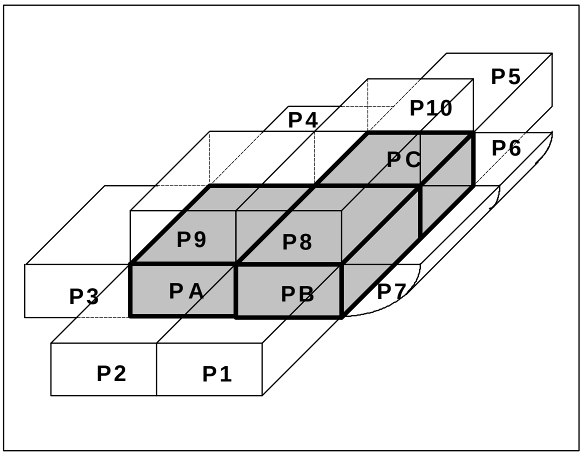

Figure 4. Spatial Position of Potentially Erectable Blocks

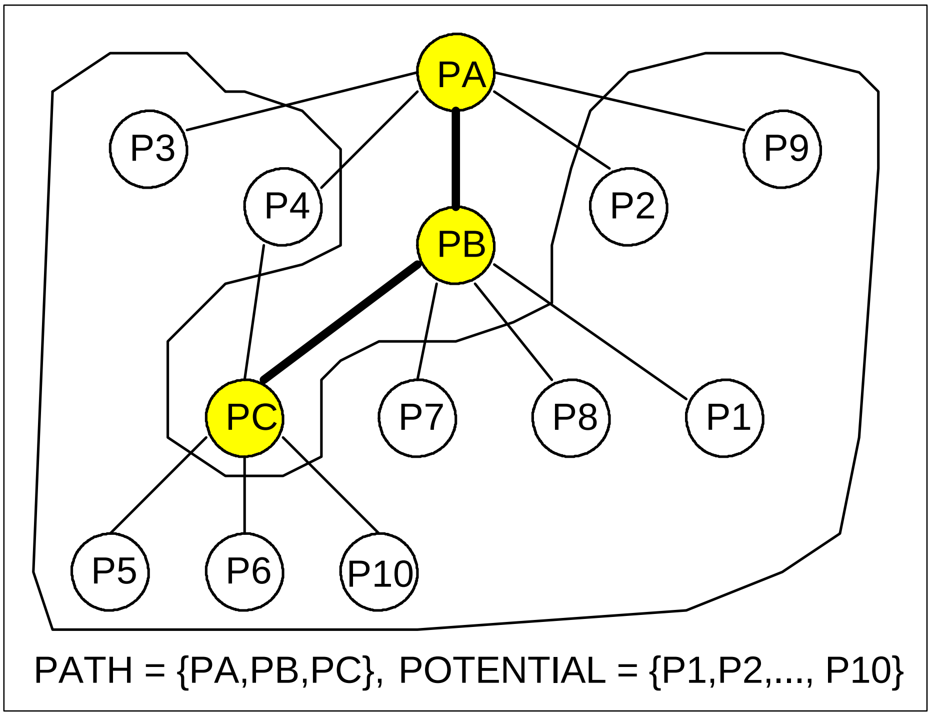

Figure 5. Partially Expanded Graph Search Space

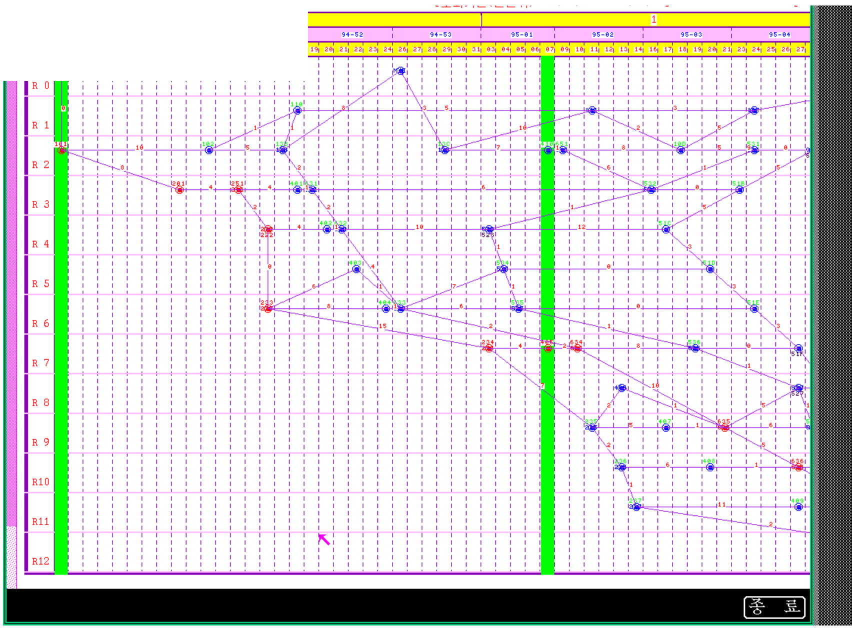

Figure 6. Erection Network Scheduled by DAS-ERECT

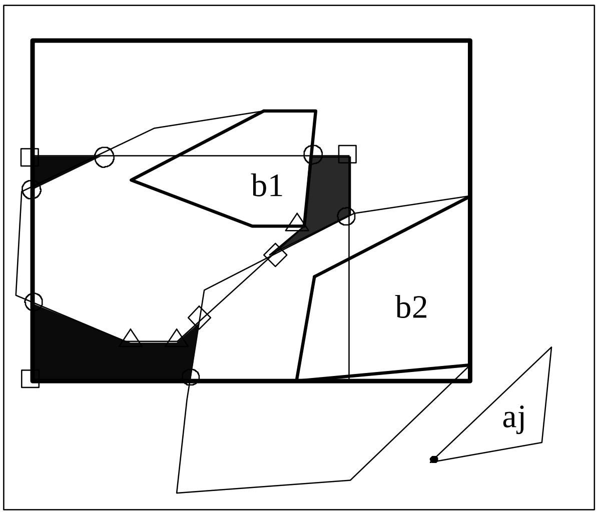

Figure 7. Feasible Locatable Space and Distinctive Locatable Points

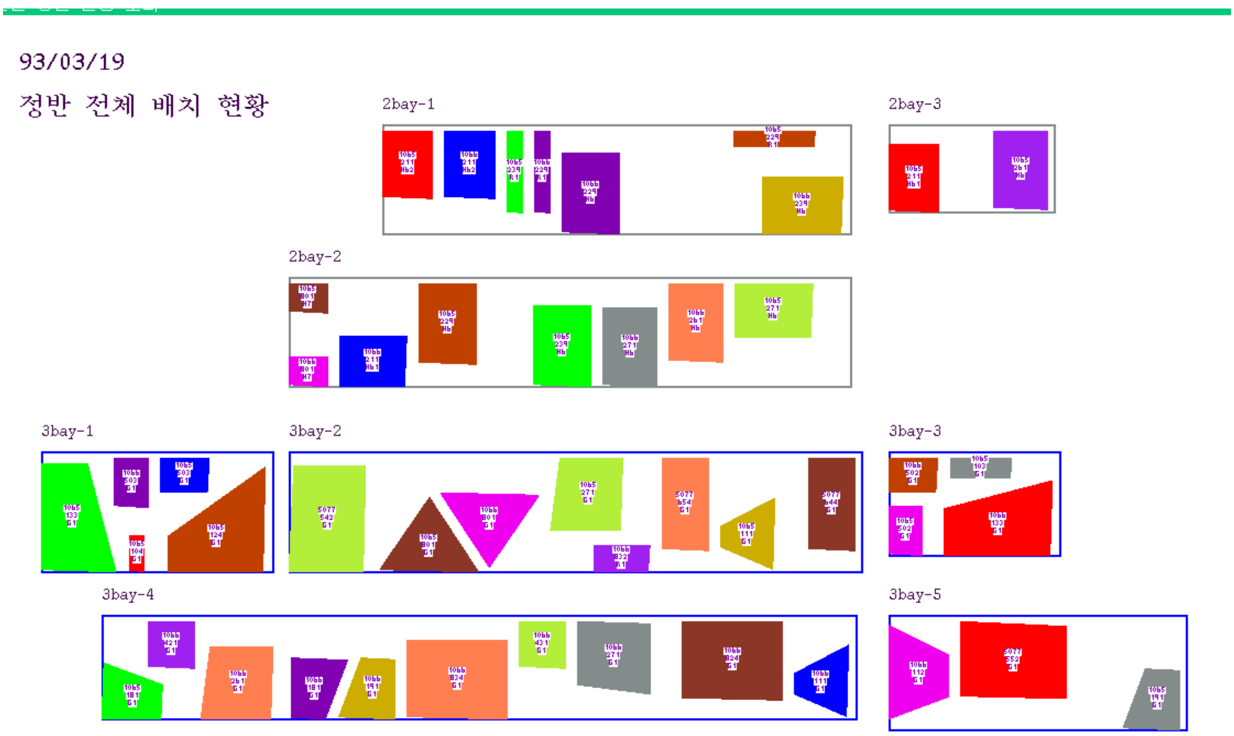

Figure 8. An Output Screen Showing a Snapshot of Spatial Layout in DAS-CURVE

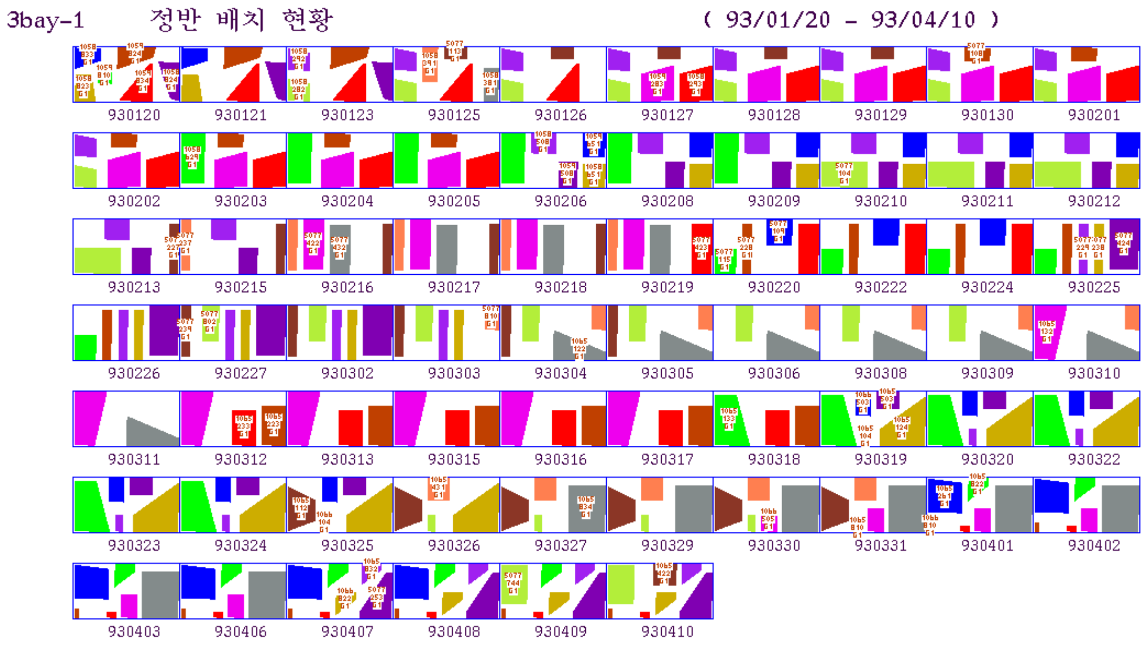

Figure 9. Output Screen Showing a Dynamic Spatial Layout of a Work Plate in DAS-CURVE

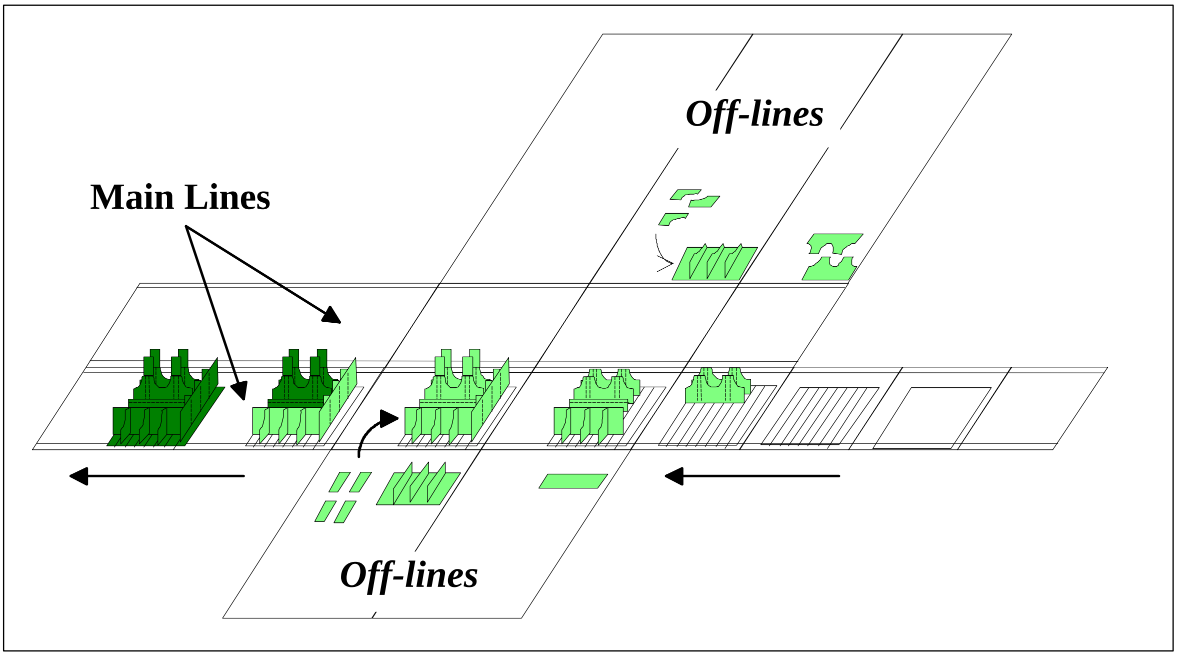

Figure 10. The Panelled Block Assembly Shop with Assembly Line and Off-lines.

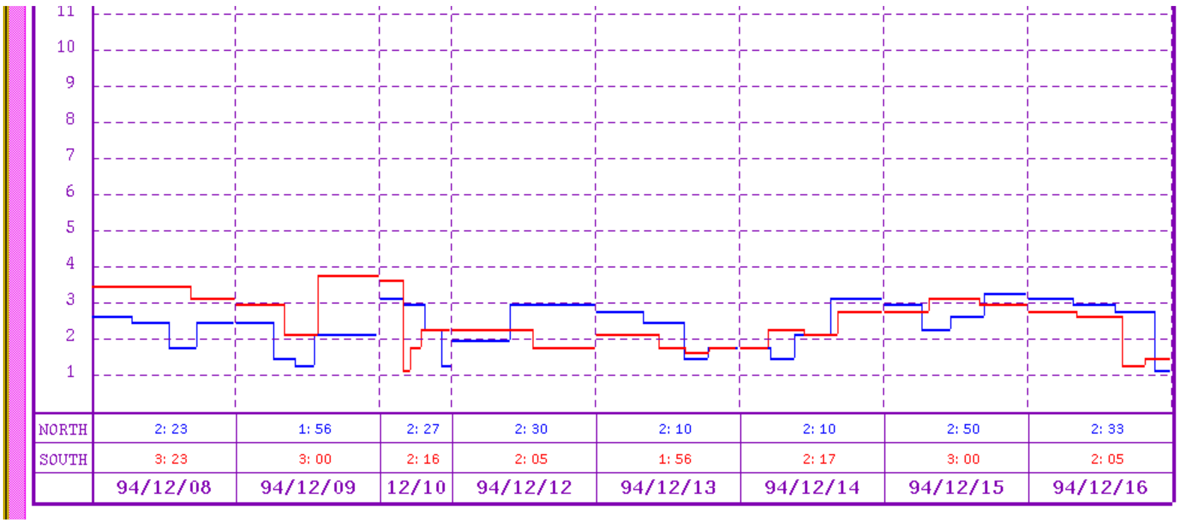

Figure 11. Output Screen Showing Dynamically Changing Cycle Time in DAS-PANEL

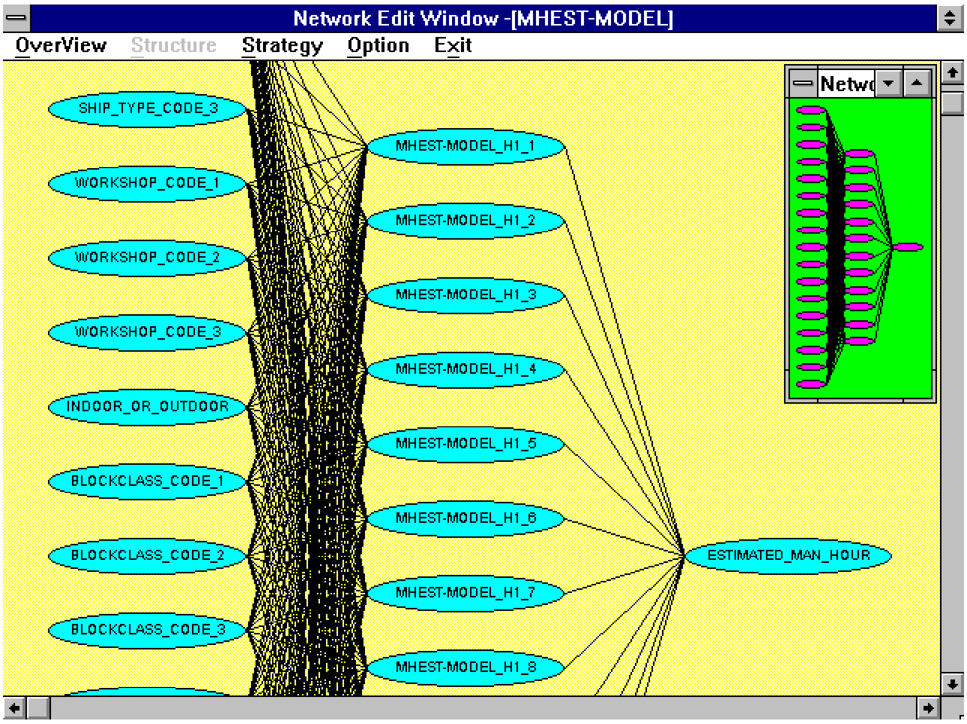

Figure 12. Neural Network Configuration for Manhour Estimation