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A CSP-based Load Leveling Algorithm for Ship Block Erection Network

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Abstract

The erection in shipbuilding is the process to assemble all the blocks one by one in certain order and requires more leveled and efficient schedule than other processes do. However, erection schedule includes too many constraints to be systemized with simple programs and constraints are changed frequently. These difficulties make it rare to find automatic erection schedule generation system with load leveling ability. In this paper, a CSP (Constraint Satisfaction Problem)-based load leveling algorithm using a maximum load diminution technique is proposed and applied to the block erection scheduling of a dock in a shipyard. The result shows that it performs better than currently used scheduling method based on empirical logics. The maximum load of welding length and crane usage are reduced by 31.63% and 30.00% respectively. The deviation of resource usage amount also decreases by 8.93% and 7.51%.

Keywords: ship block erection scheduling, load leveling, constraint satisfaction problem, maximum load diminution technique

1 Introduction

Since the beginning of 2000's, Korean shipbuilding companies have been worldwide leaders in commercial shipbuilding market. Expecting to maintain their position in the market, they are trying to improve productivity. Cost reduction can be one of good solutions for that.

Modern shipyards construct ships block by block and the erection in shipbuilding is the process to assemble all the blocks in a dock one by one in a certain order. Other manufacturing schedules are established on the basis of erection schedule and a dock in shipyard is the places where all logistics for a ship converge. Therefore block erection schedule has a crucial influence on overall shipbuilding cost. By these reasons, erection process requires more leveled and efficient schedule than other processes do.

However, erection schedule must satisfy too many constraints to be systemized with simple programs. Furthermore it has a tendency to be changed frequently like many other processes in shipbuilding. These difficulties in erection process make it rare to find an automatic erection schedule generation system with load levelling ability that is practically applicable in yards.

Therefore, currently most shipbuilding companies establish erection schedules with systems based on empirical logics and they strongly require an automatic erection scheduling system that can generate practically applicable load-leveled and efficient erection schedules (Choi 1994).

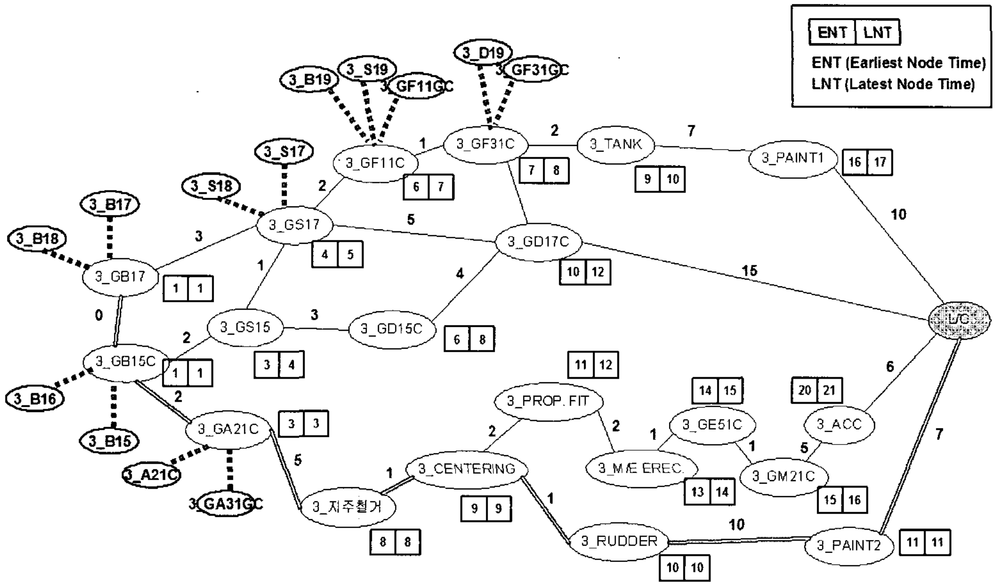

Figure 1: An example of ship block erection network which is used in shipyards. The path that consists of bold edges and light gray node is a critical path that has no float.

In this paper, a CSP-based load-leveling algorithm, which uses maximum load diminution technique and yields better load-leveled schedule compared to currently used systems, is proposed. The paper is organized as follows. In section 2, some basic concepts and techniques related to this paper are explained. They are block erection network, load balancing algorithms, and CSP. Section 3 describes related work in ship block erection scheduling. In section 4, a CSP-based load levelling algorithm is proposed. Section 5 contains experiment results and section 6 concludes the work.

2 Background

This paper deals with a kind of interdisciplinary problem which embraces computer science, industrial engineering, and naval architect. Thus some explanation on concepts or techniques related to each field is required. In this section, brief explanation on ship block erection network, CSP, and load leveling algorithm is given.

2.1 Ship Block Erection Network

The ship block erection network represents the sequence of block erections, and the work period of each erection. The network is constructed with the Program Evaluation and Review Technique (PERT) method, and it is made out differently according to the characteristic of shipyards. The block erection network usually follows Activity on Arc (AOA) method to mark an activity on an arc as described by (Badiru 1996) and (Finch 1995). Fig. 1 shows an example.

The schedulers, scheduling experts of shipyards, decide the block erection workday and define the erection sequences for each block with reference to a block erection network. This process, decision of erection workday using the block erection network, is called erection scheduling. Erection workdays for all blocks are decided through the erection scheduling so that ships can be launched in a certain period that is defined in the master ship-building schedule of the shipyard.

To build a block erection network, the Earliest Node Time (ENT) and the Latest Node Time (LNT) of each node must be found out by forward calculation and by backward calculation respectively. The margin between LNT and ENT is called "float" and blocks without float can be a node of a critical path. After identifying a critical path, the schedule for the erection of other blocks that have float is decided in order to level the workload on the basis of the critical path.

2.2 Constraint Satisfaction Problem (CSP)

A CSP is a problem which requires value assigning without violating any given constraint. It is formally defined by a set of variables and a set of constraints. Each constraint involves some subset of the variables and specifies the allowable combinations of values for that subset (Russel and Norvig 2002).

A CSP can be formulated with a constraint graph. In a constraint graph, nodes and edges correspond to variables and constraints respectively. A solution of a CSP is a complement assignment of values to all the variables satisfying all constraints of the problem. Values are assigned to variables in the order of a graph traverse, which is usually depth-first search. Even with brute force approach, which means non-intelligent approach, values can be assigned to all the variables but it suffers from exponential time complexity that means "impracticable" for real world application. To solve this problem, many generic heuristics for CSP have been developed and they show reasonable performance in solving problems. If a problem is treated as a CSP, many useful successor functions and goal test functions, which have been developed with smart heuristics, can be easily used. This can be a good reason for formulating a problem as a CSP.

It also has exponential time complexity to find the optimal solution from CSP solutions. Therefore it is impossible to find the optimal solution in a practical time if there is sufficiently large numbers of variables. The CSP for load leveling of block erection network has such number of variables and thus an approximate solution is selected as a practical one, which is given by solving CSP's with gradually strengthened constraints.

2.3 Load Leveling Algorithm

Load leveling is the process of determining schedule dates when (production) activities should be performed guaranteeing to demand for resources smoothly and to avoid exceeding given limits or availability of resources. The resources involved in activities can be either finite or infinite.

Load leveling is important to improve productivity of shipyard and has been accomplished through minimizing an index representing productivity characteristic. Generally this process is carried out through minimization of deviation and load index, the value that divide the standard deviation of load by the average of load.

However, minimization of deviation value has some shortcomings. First, it requires many works changed to get the minimum deviation. Second, it takes a long time for computation. Finally, two load schedules with a good standard deviation can have an undesirable maximum load distribution (see Fig. 2). The thick dotted lines in Fig. 2 specify the limit value of resources, and Fig 2 shows a successful deviation minimization satisfying resource constraint. But some resources will be excessively used causing inefficiency. In this case, load leveling using deviation minimization has been accomplished on the whole process, but the problems such as taking an overtime work and investing additional resources for manufacturing would be broken out. Therefore, maximum load decrease is also required as well as deviation minimization.

In this sense, maximum load diminution scheme can be a good alternative for deviation minimization scheme. It decreases the maximum load continuously until the value goes under certain point. It is on the two assumptions: (1) if the maximum load decreases, mostly the deviation does also; (2) it is more important keeping resource limit than getting a good deviation.

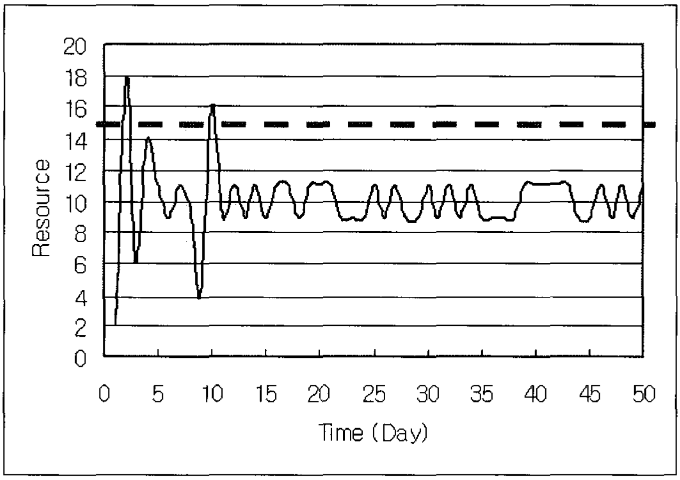

Figure 2: An example with good deviation and excessive maximum load

3 Related Work

This paper solves sequence generation and load leveling in ship block erection scheduling. For load leveling of ship block erection network, previous work usually solves the load levelling problem on the basis of operation research (OR) but this approach has difficulty in formalizing problems which include many constraints. Moreover, it is also difficult to find solutions in a practically short time using only optimization method because erection process scheduling is a combinational optimization problem that has exponential time complexity.

To overcome this, a heuristic, which gradually reduces the maximum load on resources and brought a focus on the load balancing of goliath crane, one of the most important resources in shipyards, is used by Lee (Lee and Kim 1995). Also a methodology to evaluate erection mechanism considering equipment change time and the efficiency of equipment application is proposed by Back (Back 1999).

Concerning to erection sequence generation, Genetic Algorithm with adjacent block information is used to generate erection network regarding overtime work (Kim et al 2002) A CSP-based multiple project scheduling technique is introduced by Lee (Lee and Chung 1999) but it focuses on minimizing the project duration.

4 A CSP-based Load Leveling Algorithm Using Maximum Load Diminution Technique

In this section, a CSP-based load leveling algorithm that gradually diminishes the maximum load for load leveling is proposed. Although, the proposed algorithm will not assure the optimum solution for deviation minimization, it can be practically used for an erection scheduling, which is in the stages of mid-scale scheduling, because it can generate quite reasonable result, leveled load, in a short time.

4.1 CSP Formulation of Erection Scheduling System

A great part of block erection process consists of manual works and it has many irregular works and furthermore, erection scheduling is a typical combinational optimization problem. To solve this, ship block erection scheduling problem is regarded as a CSP which involves discrete variables with finite domains. Each variable represents the assigned date for an activity in block erection process and its domain is float, the affordable working date range for an activity.

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Procedure Load-levelling (CSP)

Variables:
 CSP            the given Constraint Satisfaction Problem;
 csp_sol        a solution for CSP given by CSP_Solver();
 ML             list of the maximum load of each resource;
 Candi_ML       Candidate of the most diminished ML;

Functions:
 ExtractML(CSP); // returns ML from given CSP
 DecreaseML(CSP,i); // decrease the maximum load of the resource
with index I;
 RestoreMR(CSP,i); // restore the maximum load of the resource with
index i
 CSP_Solver(CSP); // returns a solution if any, else returns NULL;

Begin;
// Initialize the variables
 For each i
 ML[i]:= A Very Large Number;
 Candi_ML[i]:=0;

// Diminish the maximum load until there is a solution for the given
CSP
 While [Candi_ML!= ML]
        Candi_ML:=ML; // Copy ML to Candi_ML
        For each i
               DecreaseML(CSP,i);
               csp_sol:=CSP_Solver(CSP);
               if (csp_sol == NULL) RestoreMR(CSP,i) ;
```

Figure 3: Load levelling by CSP-based maximum load diminution

To construct the constraint graph for given CSP, the ship block erection scheduling problem, variables that have common domain values with any other variables are selected. Those variables become nodes in the constraint graph. Edges can be naturally defined through connecting two variables which have intersection between their domains.

Minimum Remaining Value (MRV) heuristic and Least Constraining Value (LCV) heuristic is used to solve the given CSP efficiently. Forward checking scheme is also used. Because block erection scheduling problem is a discrete and finite CSP, MRV is easily applied by counting the number of domain values remaining. For LCV, the estimated resource consumption of each node that is linked to current node is calculated. The estimated resource consumption for a node is represented as the mean of ratios of remaining value to maximum value of each resource when that node is selected. The node with the lowest estimated resource consumption is selected as the next traverse node in backtracking search.

4.2 Load Leveling through Maximum Load Diminution

Load leveling is accomplished by solving the CSP iteratively with gradually strengthened constraints. Fig. 3 shows the algorithm of CSP-based maximum load diminution proposed.

First, a solution that is derived from sufficient resources is generated and then the maximum load value for each resource is identified. In next step, all maximum load values decrease, which is identified in the first step, by "one unit" and a search is carried out to find a new solution that does not excess any of maximum load values that are decreased in this step. The one unit means the minimum required resource for a work in the ship block erection process. If a block operation requires at least 2 crane usages and 300m welding, the one unit decrease will reduce maximum crane usage and welding length by 2 and 300 respectively. This makes it possible to skip meaningless iteration. When the reduction of all maximum resource loads can not generate a solution, all maximum resource load values are recovered and then the load for the next resource is decreased. All decreases that can not generate a solution are recorded and values before decrease are fixed as the maximum loads for corresponding re-sources. In this way, maximum loads for all resources can be diminished and the distribution of the load can be leveled.

Table 1: The result of maximum load diminution after 23 iterations

Iteration	Welding		Crane usage	
	Max length	Deviation	Max usage	Deviation
1	3386 m	146.32	20	9.72
3	2889 m	145.02	19	9.63
5	2765 m	136.87	18	9.58
7	2737 m	136.42	17	9.02
9	2683 m	134.73	15	8.99
17	2489 m	133.25	14	8.76
23	2317 m	124.84	14	8.33

Table 2: The comparison of results from currently used system and proposed algorithm

	Scheduling expert	Proposed algorithm	Improvement
Maximum Welding Length	3415 m	2317 m	47.39% ↓
Welding Length deviation	142.2798	124.8357	13.97% ↓
Maximum crane usage	19	14	35.70% ↓
Crane usage deviation	9.6616	8.3311	15.97% ↓

5 Experiment Result

The proposed algorithm is applied to block erection scheduling of a dock in a real shipyard The result shows that the proposed load leveling algorithm performs better than currently used scheduling method that is based on empirical logics.

Usually, three or more ships are constructed in a dock simultaneously and this construction scheme is called "tandem building." Ships are constructed in a "dry dock" and than launched into the sea. For launching, the dock should be filled with seawater and the concurrently constructed blocks, which are parts of other ships, are floated together with the completed ship. Then, the ship leaves the platform and the dock becomes dry again arranging uncompleted blocks, which are called tandem blocks, into appropriate positions for further construction. The period from removing water from dock to launching a ship is called a "batch."

Four assumptions are made to apply our algorithm to shipyard scheduling practice: (1) constraints on erection process are welding length and the number of goliath crane usages, (2) the number of goliath crane usages is increased by two when two cranes are used simultaneously, (3) port and star-board sides of blocks are erected in the same day, and (4) scheduling is done over whole batch with five ships and every ship can stay no more than 26 days in dock.

Table 1 shows the result of load leveling by the proposed algorithm and Table 2 compares this result with the result from currently used system. As shown in Table 1, the maximum load of welding length and crane usage are reduced by 31.63% and 30.00% respectively after sufficient iterations. The deviation also decreases by 8.93% and 7.51% respectively. These imply that the iteration of maximum load diminution induces the decrease of deviation. Compared to currently used scheduling system in the shipyard, which is based on empirical logics, the result shows over than 35% in maximum load reduction and 13% in deviation reduction respectively.

The shipyard makes its erection schedules and networks using accumulated data which is extracted from their experts' construction experience rather than using PERT/CPM method. The erection scheduling process requires schedulers' considering many factors and constraints simultaneously and this is a challenging job even for experienced schedulers who are responsible for generating final schedule. The experiment result shows that the proposed algorithm can solve this problem and generates more efficient erection schedules.

6 Conclusion

This paper describes a load leveling algorithm, which uses CSP-based maximum load diminution technique, for ship block erection scheduling. It is applied to the block erection scheduling process of a real shipyard and the result is compared with that of currently used scheduling system. By the comparison, the usefulness of the proposed algorithm is verified. And also the algorithm is expected to improve the overall productivity of the shipyard. Instantly, it will reduce overtime work that is usually caused by unreasonable schedules requiring excessive resource. Moreover it is also possible to use the proposed algorithm in other leveling process of shipyard such as equipment install process that uses backward scheduling. For the long run, leveled workload and resource load can be a good basis for long-term equipment capacity planning and manpower planning.

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