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조선소 소조립 주판 배치 시뮬레이션 기반 공간 계획 시스템 개발

Shipbuilding subassembly spatial arrangement planning system, a discrete event simulation based approach

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Abstract

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In the shipbuilding subassembly process, space is one of the main resource constraints limiting production capacity. To efficiently manage the space resource, how subassembly parts will occupy the workshop floor need to be analyzed before production. In this study, a methodology of controlling the subassembly space resource is proposed. In this methodology, first the impact of space on the production capacity for a given time period is analyzed. This analysis is performed through a framework of discrete event simulation modelling the subassembly process using subassembly part scheduling algorithm and spatial arrangement planning algorithm. The production schedule' s feasibility in terms of space resource utilization is examined through the simulation model. Second, a detailed subassembly part arrangement layout is generated using a genetic algorithm based spatial arrangement algorithm. The algorithm is used to efficiently utilize the work area and accurately predict the amount of area required for a subassembly production lot. After the methodology is presented, a case study of the simulation model is analyzed, and the performance of the genetic algorithm based spatial arrangement algorithm is evaluated.

Keyword :

Spatial arrangement
Discrete event simulation
Shipbuilding subassembly
Genetic algorithm

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Figures and Tables

Chapter 1. Introduction

1.1 Study background

In most large shipyards, ships are built using the hull block construction method. In this method, a ship is divided into several blocks and assembled in a dock. Blocks consist of smaller steel structures which are assembled in the subassembly stage. Because blocks are large in size and its subassembly component structures numerous, space becomes an important resource constraint in the subassembly stage. Therefore, it is important to develop methods of efficiently utilizing space in the subassembly work area.

Subassembly parts are variable in size and shape, so the amount of workshop floor space required cannot be accurately determined from summing up the surface area of the subassembly parts. Before production work commences and the subassembly parts are placed on the factory floor, the foreman does not know beforehand how much space will be required to a great accuracy. Because of this lack of forecasting ability, as shown in Fig. 1, work space may be underutilized or parts of production may not be able to commence due to lack of space.

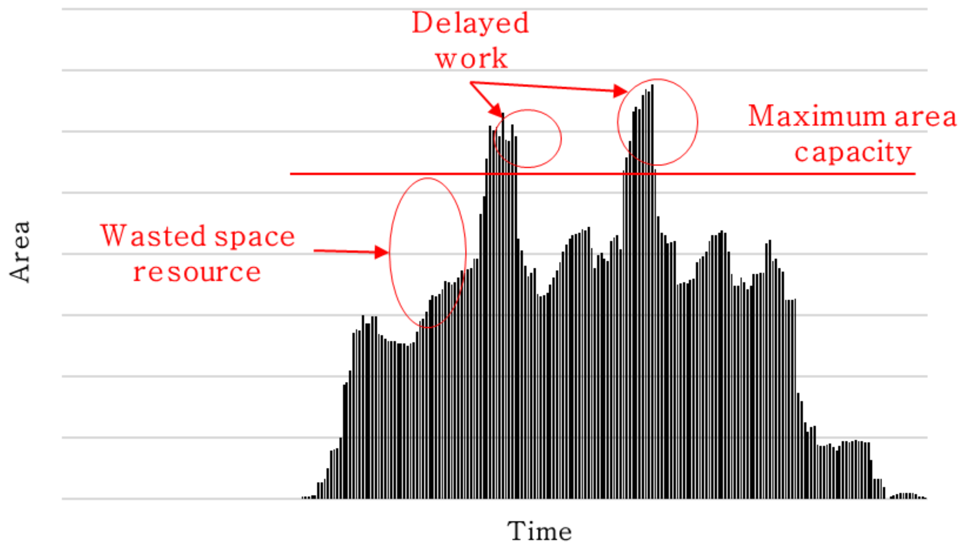


Fig. 1 Example of work delay and wasted space resource

The manufacturing capacity of each subassembly production team is estimated by the amount of work done during past production periods. Currently, in the industry, subassembly spatial constraints are only lightly examined by assuming from past experience that a certain amount of workload, measured mainly in weld length, will require a certain amount of work area. This assumption and lack of short term and long term spatial arrangement planning often leads to unexpected problems in production from temporary lack of work space or an underutilization of space leading to reduced production performance.

The current subassembly scheduling methodology is outlined in Fig. 2 and it can be seen that production goals are based on past month's production and any unexpected capacity problems will cause delays in the production. Issues in resource availability, especially space resource need to be dealt with during the scheduling phase and not the production phase.

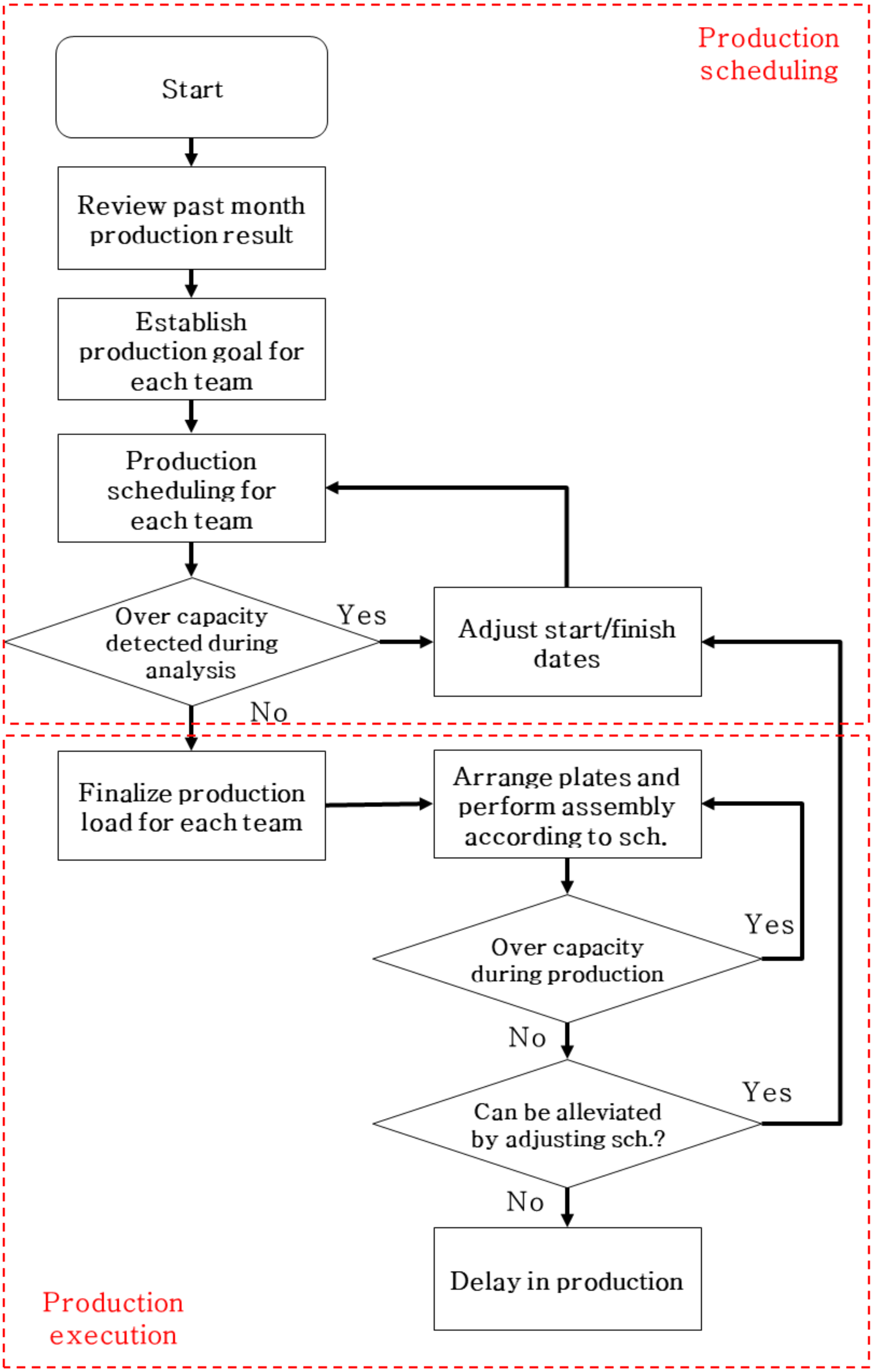


Fig. 2 Subassembly process scheduling flowchart

In shipyards, six factors determine productivity. The six factors are product, process, schedule, facility, human and space. The productivity of shipyards can be improved by introducing methods of efficiently utilizing the six factor resources. In the scope of this study, in order to efficiently utilize the space resource of the subassembly process, the locations of the subassembly parts must be space efficient and take into account various elements of the production process.

This problem of determining the position of the work-in-process parts can be defined as a spatial arrangement problem. However, not only does the position of the production parts need to be considered, but also their time in the workshop floor as well. Because the parts have start and finish dates, they do not occupy the work space indefinitely. By introducing an element of time, the problem of determining the position of the subassembly parts can be further defined as a spatial arrangement *planning* problem. In the shipbuilding industry, subassembly process's short-term spatial arrangement planning is performed only in the foreman's mind and not explicitly performed. Long term subassembly spatial arrangement planning is not accurately performed either. Schedules are created with a rough estimate of the space required by the production parts based on past production history.

1.2 Past research

Because the shipbuilding industry relies on humans to perform short term spatial arrangement planning, and long term spatial planning is not performed, various studies have been conducted to find methods of efficiently utilizing space in shipyards. Zheng et al. (2011) considered both space and time constraints to solve the block spatial arrangement planning problem. The time dimension was viewed as another space dimension to formulate the problem as a three dimensional packing problem. Eum (2008) explored spatial arrangement algorithms which maximize both the area utilization over a period of time and for specific periods in time. Kwon and Lee (2015) approached the block arrangement planning problem using mixed integer programming. The problem was formulated as a three dimensional problem with two dimensions representing the two dimensional shape of the block and the third dimension representing the start and finish times of the block. Koh et al. (2011) analyzed the spatial scheduling problem for mega−blocks by taking into consideration the manpower resources. Song et al. (2009) analyzed the production capacity of the assembly process by creating a simulation model of the production process. The positions of the blocks in the simulation model were determined heuristically and the production capacity analyzed. Koh et al. (2008) proposed the Least Contact Area methodology to determine an efficient spatial arrangement for assembly blocks. Finally, Jeong et al. (2018) proposed a method of minimizing twist shapes to efficiently create a spatial arrangement plan in shipyards.

When looking at simply the problem of arranging items in a container as efficiently as possible without taking time into consideration, there can be seen many studies in the field of nesting and bin packing problems. Solutions to nesting and bin packing problems attempt to find ways to fit as many shapes into a limited container as possible. Using a heuristic algorithm, Jeong and Jeon (2008) attempted to solve nesting problems for two dimensional irregular shapes by rotating the shapes on their vertices. Burke (2007) attempted to solve the nesting problem through efficiently generating No-Fit-Polygons and Van Dijk (2014) used three-dimensional packing problem to efficiently load containers on a container ship.

Although there have been many studies in the past investigating the spatial arrangement and the spatial arrangement planning problem, there have not been active research into applying the methodology to the subassembly process. In the industry, both short term and long term spatial arrangement planning in subassembly process is not performed explicitly, partly because there is a lack of research in establishing a guideline or framework for subassembly spatial arrangement planning. More research is needed in understanding the methodology and algorithms required to find the spatial arrangement of subassembly production parts while taking into consideration the constraints unique to the subassembly process. Furthermore, further research is needed in applying spatial arrangement planning in the subassembly process.

1.3 Research scope and methodology

In this study, algorithms and evaluation factors for spatial arrangement problems that were utilized in various fields were reviewed to address spatial arrangement planning problems in the subassembly process. The spatial arrangement algorithms were utilized to create a systematic method of evaluating and analyzing space and manpower resources in the subassembly process for a given period of time. In the methodology, Bottom−Left−Fill based spatial arrangement algorithm is developed and combined within a discrete event simulation framework to create a system to analyze the space resource utilization for a period of time. Furthermore, a genetic algorithm based spatial arrangement algorithm is developed to develop a system to create a detailed subassembly part arrangement layout.

This study proposes a system or methodology of evaluating and analyzing space and manpower resources in the subassembly process for a given period of time, with the goal of creating an accurate schedule and a layout of subassembly part locations for each day of the scheduled period. This methodology can be systemized and used by the production manager before and during production scheduling and before initiating production work. This process of analyzing the space and manpower constraints during production scheduling and creating a detailed layout of the subassembly part positions is expected to decrease delays and increase throughput through a better ability to predict and remove resource bottlenecks and more efficient use of the manufacturing resources.

Furthermore, a genetic algorithm based spatial arrangement algorithm is proposed. The algorithm's evaluation criteria determining the optimization method in the algorithm is explored. Also, the methods of applying the rules of the subassembly production in the algorithm is discussed. The proposed methodology is summarized in Fig. 3.

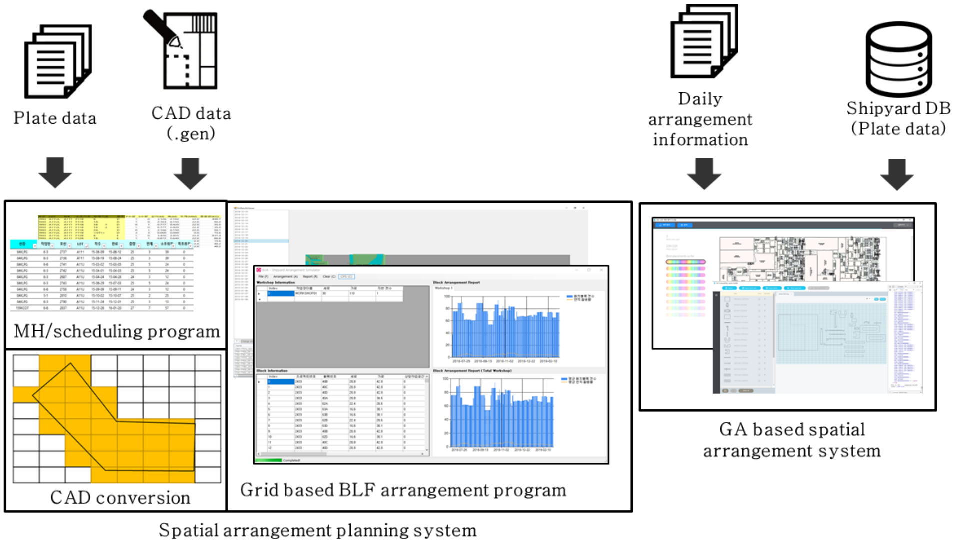


Fig. 3 Overview of proposed methodology

Chapter 2. Defining the subassembly process

In order to create a simulation model of the subassembly process, the subassembly process is defined and explained in detail in this section. In chapter 2.1, the subassembly product is defined. In chapter 2.2, the different types of work areas are defined, and finally, in chapter 2.3 the subassembly production scheduling methodology is defined.

2.1 Defining the part object

In shipyards, parts of blocks are cut from steel plates in the cutting stage and assembled in the subassembly stage. The subassembly parts are then sent to the assembly shop and assembled into blocks. The subassembly parts consists of a base plate, which lie flat on the subassembly workshop floor during production, and a set of stiffeners welded on top of the base plate. During the subassembly process, two subassembly parts may combine to form a larger midassembly structure. This process is called first level midassembly. In a similar manner, two first level midassembly structures can be combined to form a larger structure. This process is called second level midassembly. This process of building up subassembly parts into larger structures is illustrated in Fig. 4. Most production parts in the subassembly workshop finish at the subassembly stage but a few parts require first or second level midassembly.

When the steel pieces are placed on the shop floor, the position of the subassembly's stiffeners do not take up extra space because they are placed on top of the matching subassembly base plate. The foreman does not need to worry about the location of the steel pieces for parts that finish as subassembly structures. However, the locations of subassembly structures that combine to form into first or second level midassembly parts must be thought out in order to reduce unnecessary material handling time. The method of taking into account in the algorithm this characteristic will be examined in later chapter. The completed parts of the subassembly process is delivered to block assembly workshop, where the subassembly parts are assembled into blocks which make up the ship's structure.

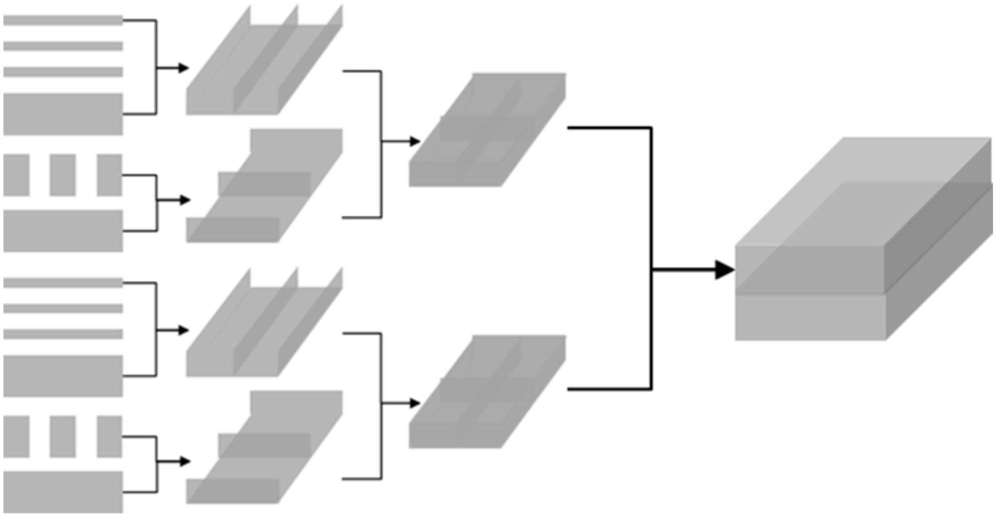


Fig. 4 Assembly structure of subassembly part

Subassembly parts are grouped into subassembly lots for scheduling and management purposes as shown in Fig. 5. A subassembly lot consists of a selection of subassembly and midassembly parts which become assembled into a similar section of a block. The grouping of the subassembly parts into lots is determined by the production planning department and the lots' production schedule is determined before delivering the production order to the production teams. Because the subassembly lots are the smallest unit that is scheduled by production managers, the individual subassembly parts' start and finish dates are determined by the foreman on the workshop floor. The foreman schedules work for the individual parts with the goal of finishing the production of all parts before the scheduled finish date of the lot. The foreman also needs to schedule the work so that space is available on the workshop floor to place the steel plates. The workshop's available production area needs to be utilized efficiently both in space and time dimensions.

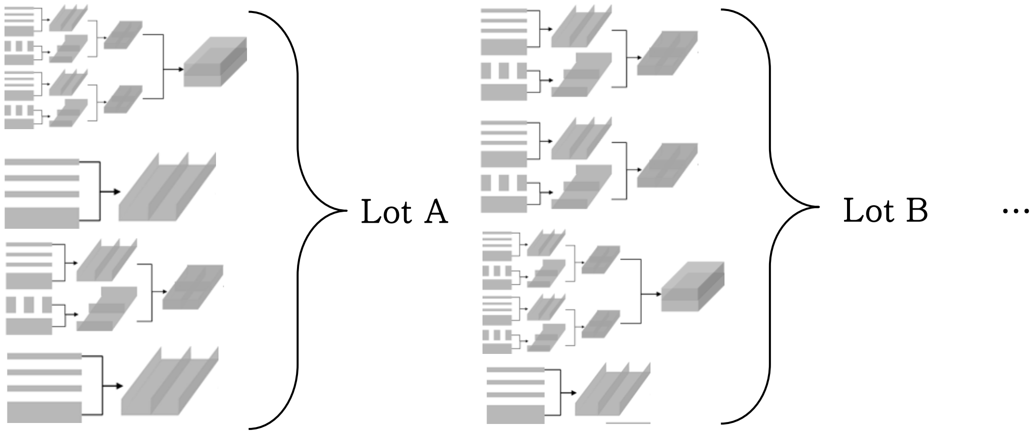


Fig. 5 Subassembly lot

2.2 Defining the workshop

There are three types of subassembly workshops as illustrated in Table 1. Fixed area workshops are areas with non-moving floors. Usually subassembly lots that require a long production time (usually containing many midassembly parts) is produced in this area. Usually, more than one lot is placed in one fixed area workshop at once. At the end of every work shift, finished parts are unloaded from the workshop. Unloading of finished parts create disjoint empty areas within the work area. In order to make better utilization of these empty areas, the subassembly parts under production are rearranged to create one large empty area. This rearrangement occurs at the end of every work shift.

Skid workshops are areas consisting of several disjoint work areas or "skids" which can be moved by the overhead cranes. When all the work for subassembly parts placed on a single skid is complete, the crane lifts the skid and moves the skid and all the subassembly parts placed on it to the unloading section of the work area. In the case of skid work area, subassembly parts with same or similar finish dates must be placed in the same skid because the parts will have to be unloaded all at once to efficiently use the skid. Because all the parts are unloaded at once, there is no need for rearrangement.

Roller work areas are areas where individual base plate can be rolled forward by hand or using cranes. In the roller work area, new parts are loaded into the starting edge of the work area and as the work progresses, plates are rolled towards the finish edge of the work area.

Type	Material Handling	Handling freq.	Rearrangement
Fix	- Loading/unloading through overhead crane (Once on work shop, no movement except rearrangement)	- Unloading 3 to 5 days after loading - Finished parts are individually unloaded at the end of shift	- After unloading, rearrangement to combine empty area
Skid	- Work area consists of several skids and skid is lifted and moved by overhead crane	- Skid is moved towards the unloading section - Usually skid is moved by one section every day	- No rearrangement because parts on skid is unloaded all at once
Roller	- Parts are moved laterally on rollers - After work is finished in each section, parts are dragged by cranes or by workers to the next section	- Parts moved by the hour	- Parts move continuously so rearrangement does not apply

Table 1 Types of subassembly workshops

2.3 Defining the scheduling methodology

The production planning department assigns the start and finish plans for the subassembly lots. The production department then decides which lots should be assigned to which production team and workshop. The production department decides this by first examining how much each production team manufactured in the past months and uses that information to determine the manufacturing capacity of each production team. Each team is assigned for the next month a workload that is similar to their previous month's output. If the total workload for all teams is under or over their capacity, then the work is distributed according to their capacity ratios. Some lots' expected required man−hour is over or under estimated than what their workload actually entails. The production department is especially careful to ensure that the distribution of the estimated man−hour to workload ratio among the subcontractors are as even as possible.

Special types of lots which require specific equipment are assigned to work areas with the equipment. Certain lots with more than average number of second level midassembly parts are assigned to the fixed area workshops. Lots with less work load and generally easier assembly work are assigned to skid and roller work areas. The subassembly production scheduling process is illustrated in Fig. 6. Once the assignment is complete, the production departments' scheduling process is complete and work commences according to the schedule.

The subassembly process scheduler assigns to each production team as close to their production capacity as possible. Scheduler also makes sure that workload through time is as even as possible. The main metric schedule manager uses to determine workload is weld length. The weld length is the length of the touching edge between two separate pieces that are to be welded together. The scheduling manager estimates the maximum amount of weld length each team can weld during a month of production and attempts to assign as close to that amount in the next month's schedule.

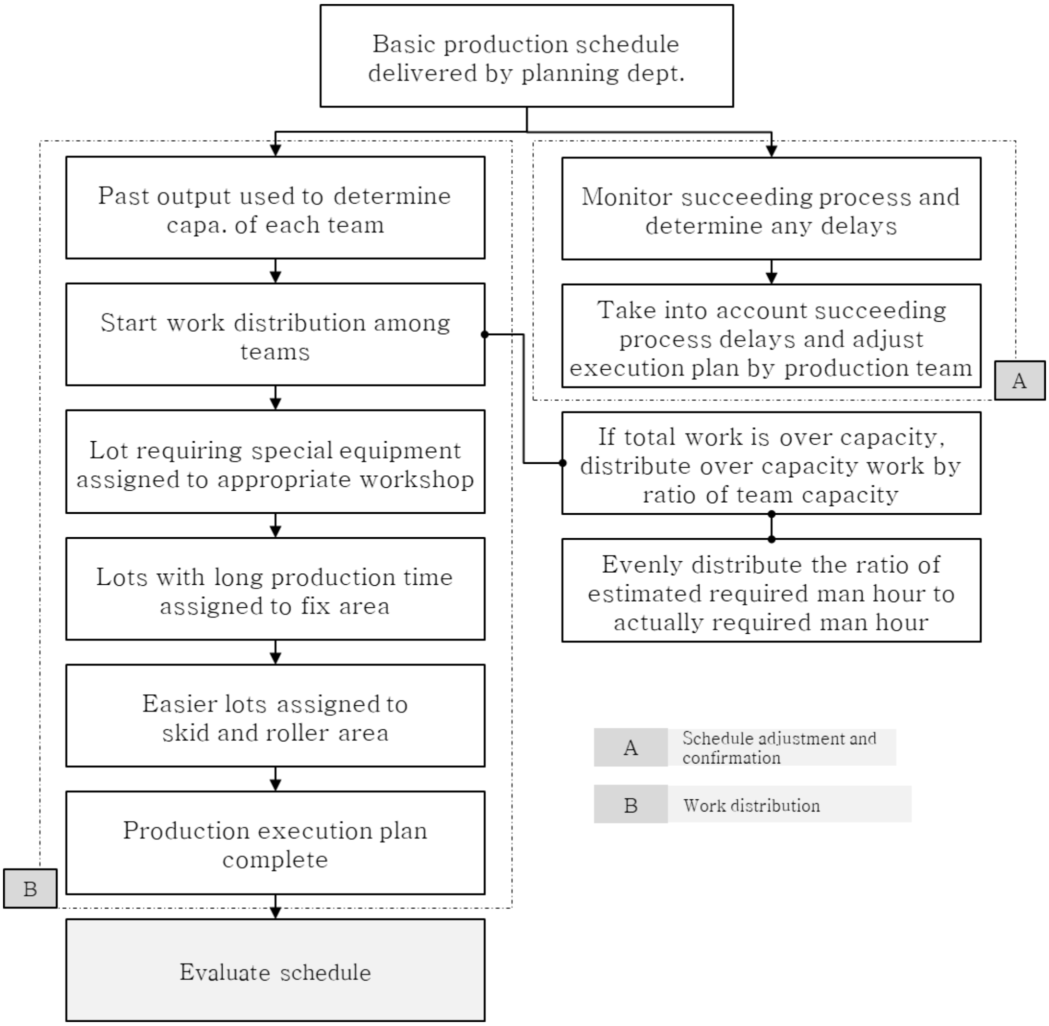


Fig. 6 Subassembly scheduling flowchart

Chapter 3. Developing the simulation model

3.1 Representing the product object

This study initially considered using the subassembly lot as the product object in the simulation model. However, because subassembly lots are composed of various subassembly parts with varying shapes, it is not possible to determine the area required for the lot without looking at the individual subassembly parts. Also, production occurs individually at the subassembly part level. Thus, it was decided to use the individual subassembly parts as the basis for product objects in the simulation model.

The identifying information of the individual pieces of the subassembly parts is obtained from the ship's bill of materials. Ship ID, block ID, subassembly lot ID, subassembly part ID and steel piece ID is used for identifying the work breakdown structure of the subassembly parts and identifying which pieces are assembled to which other piece in the subassembly part. In order to identify the base plates of subassembly parts, the ship bill of materials was filtered to find the pieces with the specific code identifying it as the base plate of a subassembly part. For further breakdown of the information used in creating the part object, refer to Fig. 7.

Column Name	Data
PROJECT_NO	Ship ID
LOT	Lot ID
PLAN_SD	Plan start
PLAN_FD	Plan finish
TEAM	Name of production team

<Production plan DB>

Column Name	Data
TEAM	Name of production team
LABOR_COUNT	Number of workers

<Production team DB>

Column Name	Data
PROJECT_NO	Ship ID
BLOCK_NO	Block ID
LOT	Lot ID
PART_NO	Steel piece ID
STAGE	WELDING STAGE
COUNT_P	Number of P parts
COUNT_SP	Number of SP parts
TACK_F/H/V/O(m)	Fit up length
WELD_F/H/V/O(m)	Weld length
PASS_F/H/V/O(m)	Pass length

<Production amount DB>

Column Name	Data
PROJECT_NO	Ship ID
BLOCK_NO	Block ID
LOT	Lot ID
SUB_ASSY	Subassembly part ID
PART_NO	Steel piece ID
MID_ASSY	Midassembly part ID

<Bill of materials DB>

Fig. 7 DB structure of the production part object

Some base plates are butt welded with other base plates after the cutting stage and before the subassembly stage. This is mainly for large subassembly base plates, which cannot be cut out from one steel plate. During the preprocessing stage of the simulation, the plate’s 3D coordinate points and ID information was used to identify which plate shapes to combine. The butt weld line was identified and the surface outline of the shapes were combined before assigning them as model objects.

The shape files for each base plates were extracted from the shipbuilder's CAD database. The shape files are originally in vector form but are converted to a raster format for input into the spatial arrangement algorithm. The vector based representation of shapes were converted to a binary grid based representation in two dimensional space as illustrated in Fig. 8. A value of one at x, y coordinate represents the presence of the base plate and zero represents lack of presence of the base plate.

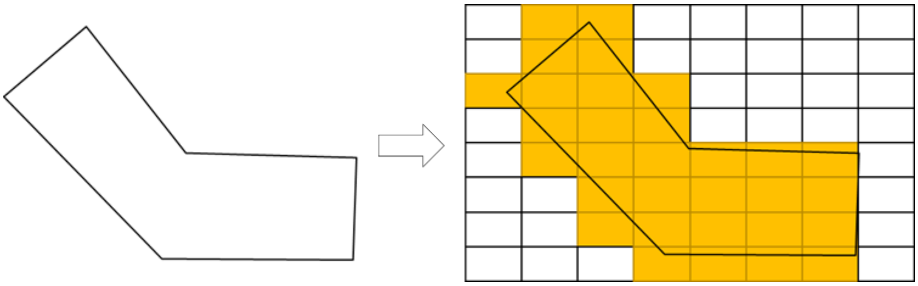


Fig. 8 Conversion of vector to raster format

Next, the man-hour required for each subassembly part was calculated and assigned to each base plate object. Because the subassembly parts within the same lot enter and exit the workshop at different times depending on availability of space and which parts get finished first, in order to accurately simulate the use of space in the workshop and analyze the use of workshop floor space over time, the man-hour required for manufacturing each subassembly part must be calculated.

The man-hour required for manufacturing each subassembly part are calculated using various data within the shipbuilder's CAD and manufacturing systems database such as the Production amount database shown in Fig. 7. The manufacturing data that has the most impact on production time were identified and their relative importance analyzed. The main data points used in calculating the necessary man−hour are weld length, fit up length, number of passes required for the weld, and the welding speed. It was decided to apply a welding speed of 5 meter/second to the fit up length, weld length and pass length to calculate the required man−hour. The calculated man−hour were evaluated by the production managers.

Finally, each subassembly base plate object was assigned a value representing the number of workers concurrently able to work on the subassembly part. This value is used during the simulation run time to determine how much man−hour resource per day to assign.

3.2 Subassembly part scheduling algorithm

Based on the calculated man−hour and taking into account the subassembly process order constraints, scheduling algorithm was developed and utilized in the simulation model to calculate the start and finish date of each subassembly part. The goal of the scheduling algorithm is to minimize late days.

In order to calculate the subassembly schedule, the required man−hour for each part, the number of available workers and the working hour per day is used. In addition, the precedence rule for midassembly parts are used. As described in the introduction, subassembly process has a precedence rule. Two or more subassembly parts may combine into one level one midassembly part, and two or more level one midassembly parts and subassembly parts may combine into one level two midassembly part. Any part that requires preceding work may not begin work until preceding work has completed. Because of this precedence rule, foreman must be careful to assign work with right timing so that workers are not left waiting on preceding work to be finished before their work can begin. There is a limit on how many people can work on a single subassembly part so workers may have no choice but to wait.

In the algorithm, subassembly parts are scheduled so that the total sum of the lateness of subassembly parts is minimized. As shown in Fig. 9, the algorithm starts by initializing the amount of man-hour available for each working day, M_d. For every day of the simulation period, the daily man-hour required for production for already placed parts are subtracted from M_d. Also, the daily man-hour per worker is added to each placed part. For parts that have added man-hour greater than or equal to the man-hour required to finish production, the parts' finish date is set to the current day. Then, out of the non-placed parts, the parts with ready date less than or equal to the current date is identified. The ready date of the part is the corresponding subassembly lot's start schedule. Out of those parts, the part with minimum expected lateness is identified. When calculating the expected lateness, the lead time of the part is calculated. The lead time for parts with succeeding midassembly process is calculated by taking into account the amount of time required for the succeeding midassembly part. If the part selected is a midassembly part and its preceding part's work has not been finished, then this part is skipped and the next part with minimum expected lateness is selected. If the part does not have preceding work or the preceding work is complete, then the daily required man−hour for this part is subtracted from M_d. If M_d is not less than zero, part's start day is set to the current day and the next part with minimum expected lateness is selected. However, if M_d is less than zero, then the algorithm either increments to the next day or terminates if current day is the end of the simulation period.

Using this scheduling algorithm, the start and end dates of each of the subassembly parts were determined. Through the scheduling algorithm, the impact on production capability due to changes in number of workers and the amount of man−hour per worker per day can be analyzed.

It was assumed that the midassembly work cannot commence until all the precedent subassembly parts are completed. However in reality, as each subassembly parts are completed, in some circumstances, the subassembly parts may be joined to the midassembly part as long as the midassembly base plate's construction is completed beforehand. However, it was determined that the difference in work area utilization due to this discrepancy is negligible in context of other discrepancies between the scheduling algorithm and reality.

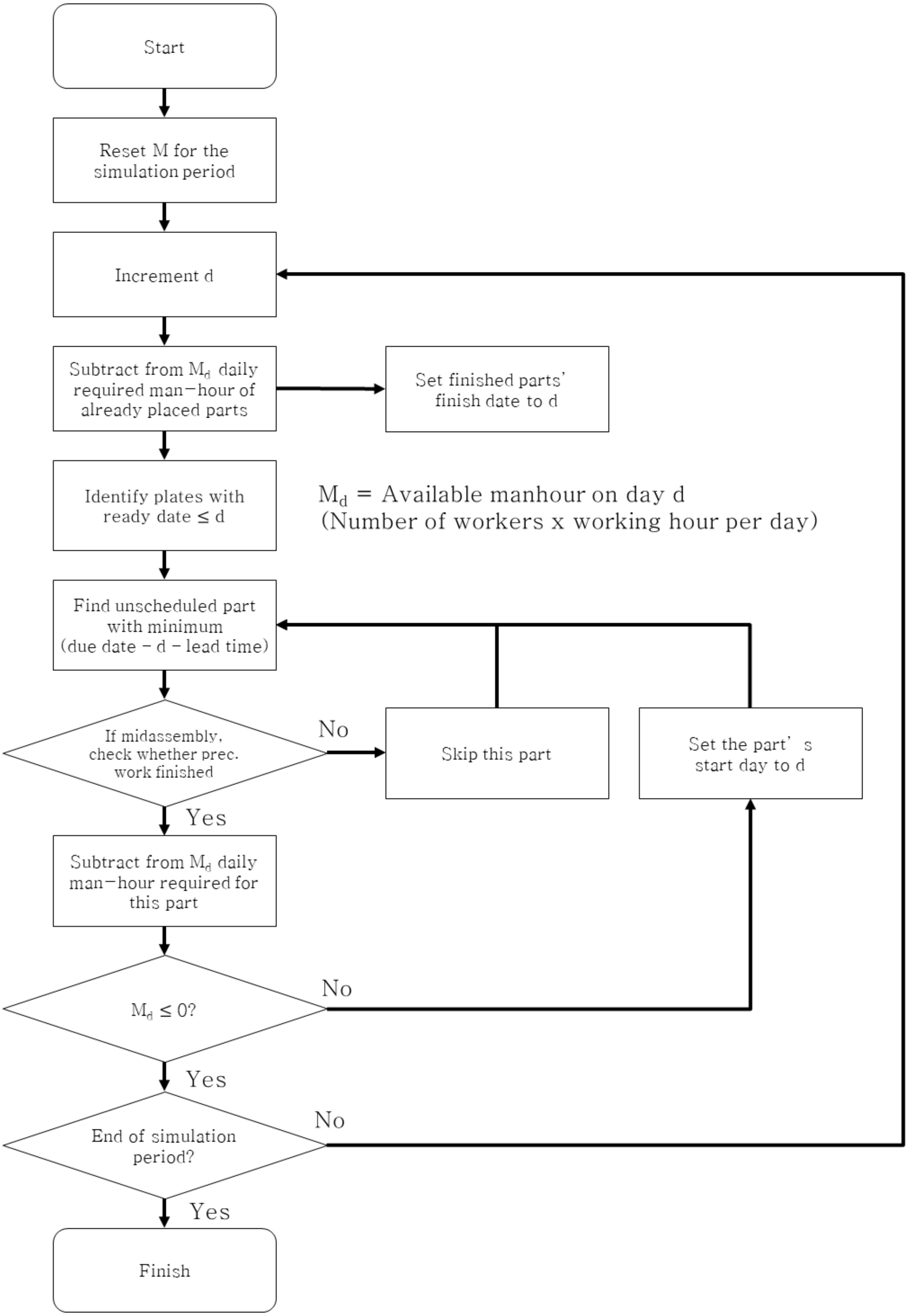


Fig. 9 Subassembly part scheduling algorithm flowchart

Note that at this stage in creating a schedule for the simulation model, space has not been taken into account. It has been assumed in the scheduling algorithm that if worker can be assigned subassembly part work, there will be enough space. The space constraint will be analyzed in the spatial arrangement planning algorithm.

The model objects and parameters and the output of the scheduling algorithm discussed in this and previous sections are then to be used as input in the spatial arrangement planning algorithm discussed in the next section. The input to the spatial arrangement planning algorithm is illustrated in Table 2.

Name of base plate shape file (pre-joined)	**Start plan**	**Finish plan**	**Lot start plan**	**Lot finish plan**	**Req. m/h**	**Work shop**	**Num. of workers**
DRT-R_FR21_33^1111^K11P^P13UL^(O56D_B;O56D_A).csv	2020-02-03	2020-02-04	2020-02-01	2020-02-07	500	A	10

Table 2 Example of scheduling algorithm output

3.3 Spatial arrangement planning algorithm

In this study, a simulation model of the subassembly process was created for the purpose of validating the feasibility of the production schedule and to find areas of production improvement. The simulation model is designed to simulate a multi−day period of production, usually longer than one month. The simulation can find the positions of each subassembly part on the work area by using the spatial arrangement planning algorithm. The purpose of the simulation model is to quickly validate the possibility of the subassembly production schedule by validating the availability of space and manpower resources.

The model has a source object element, which creates objects of subassembly parts with the information defined in the previous section. The model also contains a workshop element, which is a geometric area in which subassembly base plate object elements must be located wholly inside in order for the work to start. After the part object is placed inside the workshop element, the subassembly base plate object will then exit the workspace element at the predetermined finish date, and are removed from the simulation model at run−time.

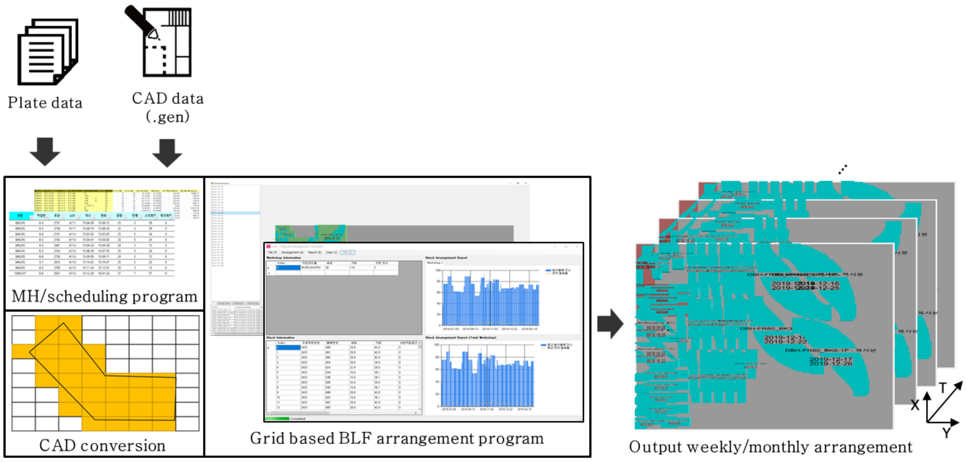


Fig. 10 Overview of the spatial arrangement algorithm

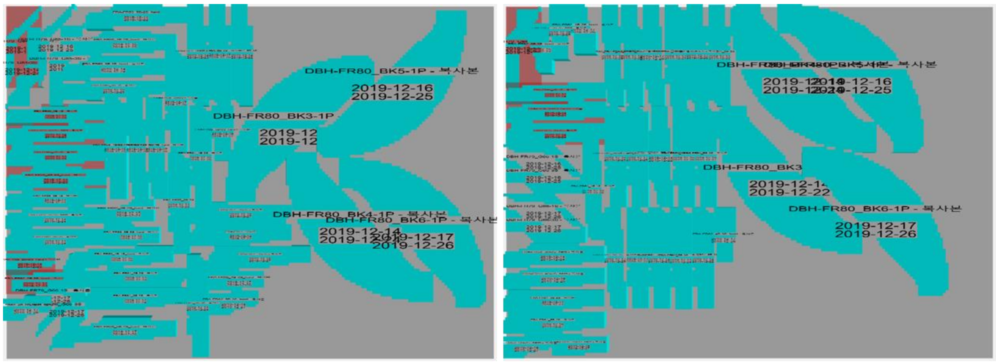
The workshop element maintains a value representing the total amount of daily available man−hour. This value is calculated from the number of workers assigned to each workshop multiplied by the amount of daily available man−hour per worker. The available man−hour constraint was used in the scheduling algorithm to determine the start and finish dates of the subassembly parts. The constraint will be used again in the simulation model to delay the start and finish dates of any potential parts which are not provided with sufficient man−hour. The scheduling algorithm has assumed space resource as not a constraint. When the simulation model runs with the schedule from the scheduling algorithm, some subassembly parts may not have enough space to start work. This may cause delayed subassembly parts to not be able to start or finish work on time because of limited manpower resource. To take account of this, the spatial arrangement algorithm will also examine the available man−hour for each day and determine which subassembly parts are assigned enough man−hour each day to start and continue work.

The workshop element also has a queue element which holds the plates yet to be placed in the workshop. The order of the queue is the order in which the spatial arrangement algorithm will determine the position and place the parts in the workshop. The order is determined by the scheduling algorithm. The spatial arrangement planning algorithm at each day takes the plate objects which are due to start that day and calculates the coordinates in the workshop element.

The schedule data and the shape information for each subassembly parts is utilized in the spatial arrangement algorithm. The algorithm represents the workshop and the subassembly part base plate shape in raster format. The geometric shapes are represented as a set of ones and zeros on a two−dimensional grid. The algorithm’s purpose is to quickly evaluate the space resource of the workspace given a specific subassembly part schedule. It was found that raster based algorithm was the most appropriate to quickly evaluate the feasibility and perform analysis of a given subassembly part schedule for a given period of time. If results are needed quicker, the size of the grids can be increased and calculation time sped up, with the tradeoff being the loss of accuracy in the representation of the geometric figures. On the other hand, if there is ample time for simulation and the user desires a more accurate placement, the grid size can be reduced. This flexibility is desired in this simulation model because the model will be used frequently and high level of accuracy in the placement layout is not always necessary.

Each plate's potential placement position is calculated using the bottom-left-fill algorithm. The shapes were rotated at 90 degree intervals and the rotation allowing the position closest to the bottom-left corner was selected.

In the manufacturing floor, every night, the completed subassembly parts are unloaded from the workshop using overhead cranes. After the parts are unloaded, the remaining area's shape is not conducive to placing new parts, thus the remaining parts are rearranged into a compact shape to better utilize the workshop floor space. The algorithm takes this removal process into account by removing all plates that finish at the current day and rearranging the plates as shown in Fig. 11. Whenever at least one or more plates are removed, the rest of the plates already placed are rearranged first then new plates are arranged. Rearrangement only takes place if there was a plate that finished the previous day. Rearrangement does not occur on the skid or roller work areas.



Before rearrangement After rearrangement

Fig. 11. Before and after rearrangement

In this study, spatial arrangement algorithm was developed to take into account the three types of subassembly workshops. For fixed work areas, between loading and unloading, the plates only move whenever rearrangement takes place after a part is unloaded. For skid work areas, all the plates placed on a skid is moved by one skid length at the end of every work shift and the items on the skid is removed when all the work on the skid is completed. For the roller work areas, new plates are only placed on one end of the work area, and at the end of every work shift, all the plates are moved as far to the other end of the workshop as possible. As shown in Fig. 12, the algorithm has taken this into account by differentiating how the plates move based on which workshop type they are placed in.

Example of entire skid moving

Example of individual plates moving on roller work shop

Fig. 12 Different plate movements according to workshop

There are two modes of running the simulation model through changes in how the spatial arrangement planning algorithm utilizes the output of the scheduling algorithm. The first mode is interested in evaluating the space resource and follows the start and finish dates set by the scheduling algorithm as long as there is space available. Once work starts for a subassembly part, it will stay in the workshop until the finish date calculated by the scheduling algorithm. The second mode reconsiders the human resource alongside the space resource. Only the start date from the scheduling algorithm is used and the finish date is independently calculated by the spatial arrangement planning algorithm. The finish date is calculated by maintaining a daily available man-hour and assigning to each subassembly part man-hour each day until the part finishes work.

When delays occur due to lack of work area, due to the delayed start of parts, certain days may require overcapacity manpower to carry out that day's work. In the first mode, even if certain days may require overcapacity manpower, the delayed parts will always maintain their production lead time set by the scheduling algorithm.

This may be appropriate if manpower resource can be applied in such a way that even if the parts under production requires overcapacity manpower, manpower can manage to carry out the work and finish on time. On the other hand, in the second mode, the finish dates of the parts will be recalculated based on the available manpower and the amount of overcapacity. This may cause some parts to finish work on a date different to the scheduled date.

There can be cases where subassembly plates cannot be placed in the workshop because the scheduling algorithm determined that, due to lack of manpower, the plates are not ready to begin work. In these cases, increase in workers will lead to increase in production because the limiting factor is manpower. However, if the scheduling algorithm determines that work can begin but there is no space on the work floor, then the subassembly part is delayed until enough space is freed up. In this case, the resource bottleneck becomes the factory floor space and work schedule may be adjusted so that space is used more evenly through time. If there is not enough space even when space is used as evenly as possible, then factory manager must take actions such as notifying preceding and succeeding processes of potential delays or increasing overtime. The scheduling algorithm determines whether there is enough manpower resource and the spatial arrangement planning algorithm allocation algorithm determines whether there is enough space resource.

The purpose of this study is to develop a framework that production managers can use to evaluate their production schedule. In this framework, production managers are deciding which subassembly lots to assign lots to each production team and the manager evaluates whether the assigned schedule is feasible or if improvements can be made on the schedule. The simulation model therefore assumes that work is assigned to each team and is simulating the work in each team with space and manpower resource constraints. Within the program/algorithm, welding speed, maximum man-hour available to each worker, and the number of workers can be adjusted to create various drafts of the production schedule.

3.3.1 Factors in evaluating algorithm result

Various evaluation factors can be applied to evaluate the spatial arrangement results. Among these, the area utilization, which represents the ratio of the total projected area of the placed products to the total work space area, is frequently used. However, area utilization only makes sense for evaluating a single point in time arrangement. For a spatial arrangement planning where arrangement changes through the course of time, area utilization evaluation criteria needs to be altered. By considering the time dimension, area-time utilization evaluation criteria can be used. Area time utilization can be calculated by multiplying the lead time of each arrangement item by its area and dividing by the total work area multiplied by the period of time under evaluation. This will provide an average area utilization over a period of time. However, with this approach it is difficult to evaluate the variance of area utilization for each time period. For this, the area utilization can be calculated for each time period and the variance of the value calculated.

Furthermore, the total sum of late days for each subassembly part can be another evaluation factor. Production managers will be most interested in the total late days of their production. They will likely attempt to adjust their schedule or the capability of the workshop to reduce the likelihood of late days as much as possible.

3.4 Simulation case study and analysis

In this section, the simulation model described in previous section is used to analyze a production period in the subassembly plant. H shipyard’s subassembly process was simulated for the one month period between December 31th 2019 and January 31th 2020. The simulation period contained 844 subassembly and midassembly plates in 30 subassembly lots. The plates that needed to be joined together before subassembly stage were handled and the shapes combined. The start/finish dates, the lead−time of each plates and the order they are to be inserted into the model were determined using the scheduling algorithm. The spatial arrangement plan was created using the spatial arrangement algorithm. The target workshop was a fixed type workshop with dimension of 200 meters by 10 meters. In the arrangement algorithm, each grid was set to 25cm in size. This was considered appropriate because the plates were mostly larger than 200cm in size so detail was not lost in the overall shapes of the plates.

First, the simulation model was run in the first mode, by taking into account only space. The spatial arrangement planning algorithm generated a schedule without manpower constraints. The simulation model will delay the start of parts when there is no space but the delayed part's lead−time set by the scheduling algorithm did not change. In this scenario, once a plate is placed, the lead−time calculated by the scheduling algorithm is used to determine how long the plate remains on the workshop floor. The plate will remain on the workshop floor for the duration of the lead−time. The simulation model will place the plates according to the order determined by the scheduling algorithm.

For the period of one month of subassembly process simulation, it was determined that the start date of six subassembly parts were delayed due to lack of space but there were no subassembly parts that did not finish before the due date (subassembly lot's finish date). Even though the six subassembly parts were delayed in their start, there was enough time before the due dates.

In terms of space utilization analysis, as shown in Fig. 13, the date with highest space utilization was January 14^{th} and the lowest utilization was January 8^{th}. The six delayed plates' scheduled start date was January 14^{th} but as evidenced by the high space utilization on that day, there was not enough space and the start was delayed to January 15^{th}. On January 14^{th}, area utilization reached 80%, and it was determine that even at 80% utilization, delays occur due to lack of space. Thus for this simulation period, it was recommended that the production manager take action if the production plan requires more than 80% of the factory floor to be used up by the production parts.

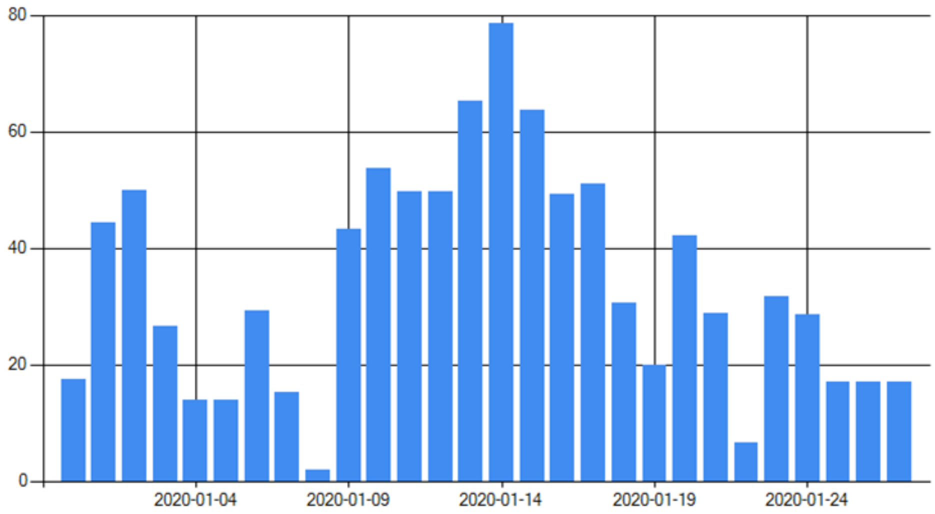


Fig. 13-1 Area utilization of simulation result (Mode 1)

Fig. 13-2 Placement result of highest area utilization day (above) and lowest area utilization day (below)

Next, the simulation was run in the second mode, where both space and manpower are considered in spatial arrangement planning algorithm. Thirty seven workers were assigned to the work area as before and it was assumed each workers worked 8.6 hours per person per day for a total of 318.2 hours per day. This value was assigned to each of the parts that were placed in the workshop and their finish dates determined when each part was assigned the necessary man-hour to finish production.

It was determined that in this simulation, fifteen plates did not start on their scheduled start date, but no plate finished after its due date. The period of highest space utilization was January 20th at 83% area utilization, as shown in Fig. 14, similar to the previous simulation.

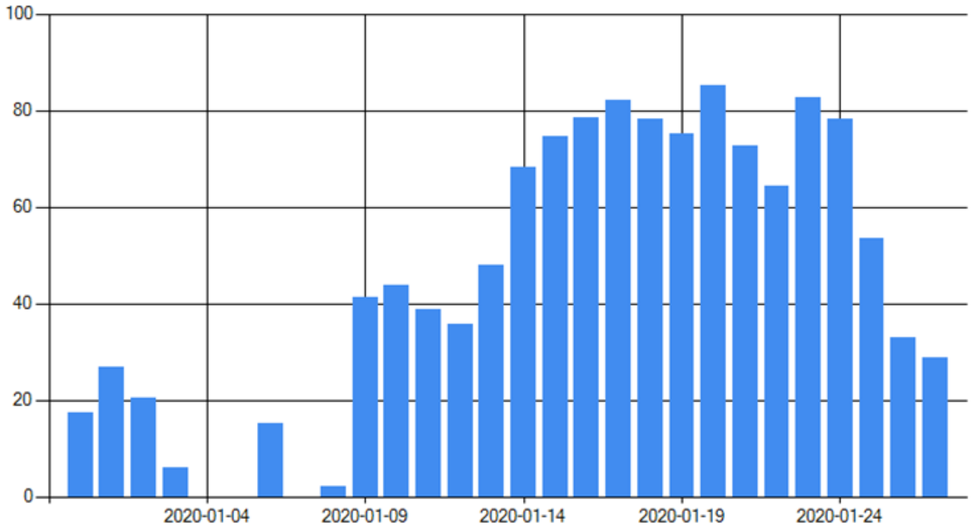


Fig. 14-1 Area utilization of simulation result (Mode 2)

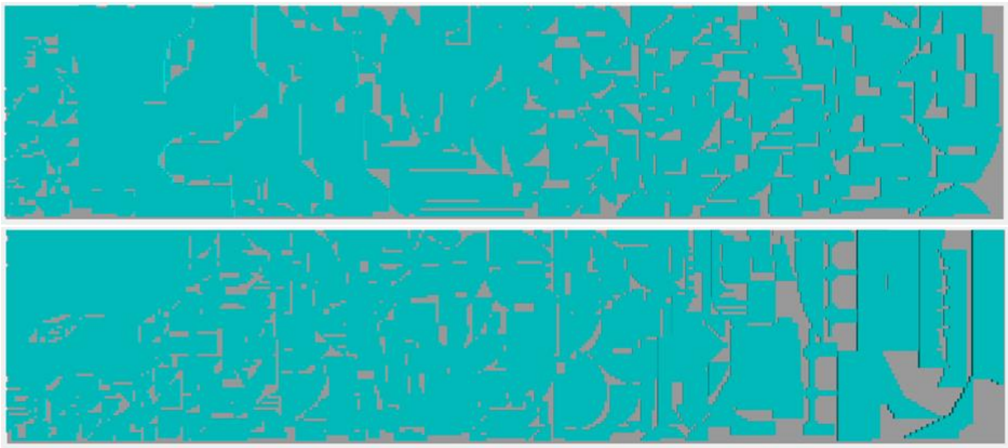


Fig. 14-2 Placement result of the two highest area utilization days

(Above : January 20th 2020, Below : January 23rd 2020)

It can be deduced from the above analysis that during the simulation period, manpower is more of a resource constraint than space. It is recommended that manpower is increased or schedule adjusted to balance out the load on manpower and space.

In order to reduce the number of plates with delayed start, a hypothetical scenario in the simulation model was created which adjusted the subassembly lot schedule to have more lots start and finish earlier. This was done to reduce the load in the end of the simulation period near January 20th of the simulated period. After this adjustments, there were no delayed plates and maximum area utilization decreased as shown in Fig 15.

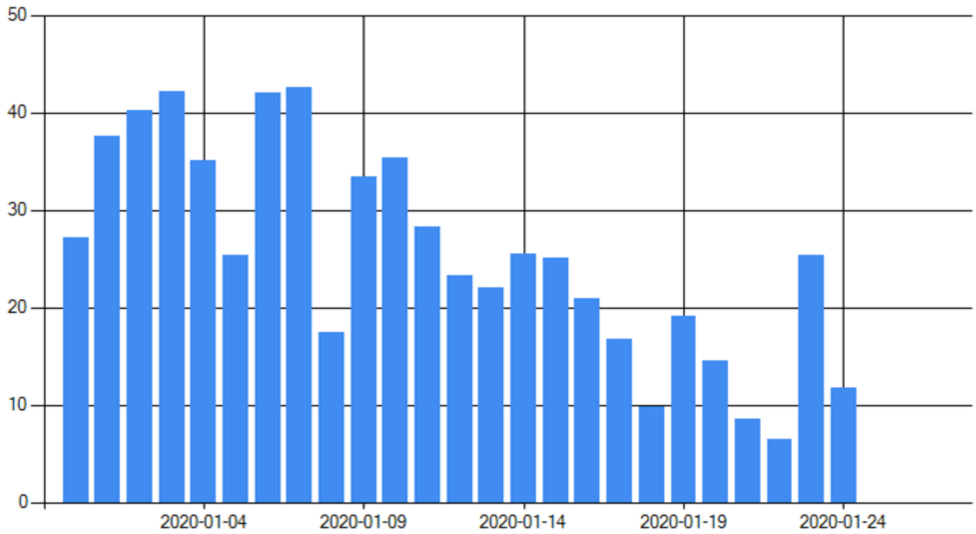


Fig. 15-1 Area utilization of simulation result (Hypothetical scenario)

Fig. 15-2 Placement result of the two highest area utilization day (Above : January 6^{th} 2020, Below : January 7^{th} 2020)

3.5 System based on simulation model

The main purpose of the subassembly simulation model is to evaluate space and manpower resource utilization and its impact on production throughput and delays. The model is designed to be used as an ongoing analysis tool. In this section, an analysis was performed for a specific period, but the simulation model user, i.e. the production manager, will perform this type of analysis on an ongoing basis to evaluate and adjust the production schedule, and evaluate potential space and manpower resource capacity of the subassembly process.

The simulation model was packaged into a system which can be used on an ongoing basis and the result page of the system is shown in Fig. 16. The system can be utilized the following way. The system can be used to create or validate schedules based on space and manpower resource utilization or capacity. Based on the weekly and/or monthly subassembly base plate arrangement layout and the weekly and/or monthly space and manpower utilization, production schedule can be created or validated. If there is a delay or a late finish date is expected, space and manpower resource constraints can be analyzed to discover the cause and solution to the problem.

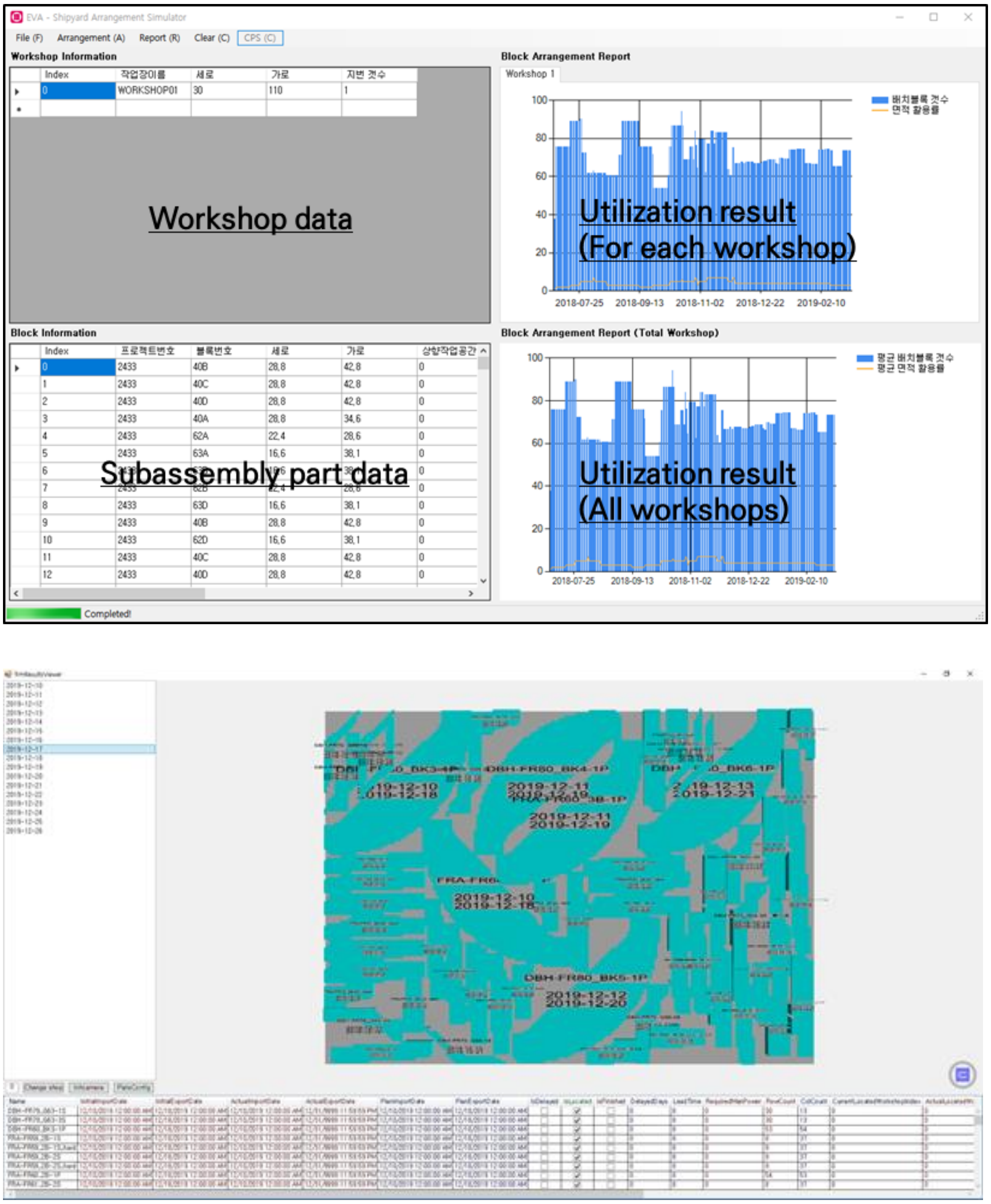


Fig. 16 Result page of the simulation system

Using this system, the space utilization for each day of the simulation period can be analyzed. If there appears to be abnormal high utilization around a period of low utilization, ways of adjusting production schedule to balance the space utilization load can be examined as illustrated in Fig. 17. Also the production manager can visually analyze the arrangement of plates each day and make more informed judgments on controlling the production floor.

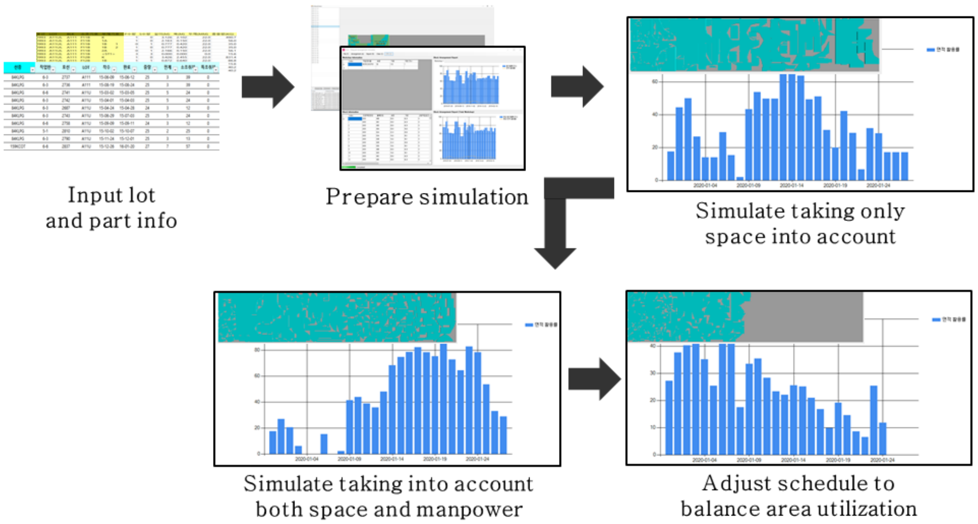


Fig. 17 Utilizing the simulation system

Chapter 4. Detailed spatial arrangement

4.1 Motivation and relation to simulation model

In the previous chapter, the subassembly process simulation model and the spatial arrangement planning algorithm was discussed. The spatial arrangement algorithm is suited for running within the simulation model. However, this study is also motivated in building an algorithm which produces subassembly part arrangement layouts in a level of detail and accuracy such that the field workers can use to lay the base plates on the workshop floor. In this study's proposed methodology, after the space and manpower resource is analyzed for a period of time and the subassembly lot and parts that can be placed in the workspace determined, a detailed layout of the subassembly part location for specific points in time is created. This layout may be used in the workshop floor as a guideline to place the subassembly part base plates. In order to build a subassembly part arrangement layout with a high level of accuracy, a spatial arrangement algorithm with a different composition and evaluation criteria was developed.

In the field, the utilization of workshop floor varies depending on the skill of the worker arranging and placing the parts. This can sometimes lead to less than acceptable use of floor space due to wasted space in between irregularly shaped parts. Also, before the lot is arranged on the floor, the total required space must be accurately predicted. If this prediction fails, some parts may not be able to be placed and production work may not be able to be carried out normally. By utilizing the detailed layout creation algorithm, one can expect a consistent high utilization of work area and an accurate estimation of the work area required before subassembly part arrangement commences.

The first difference between the algorithm discussed in this chapter and the algorithm used in the simulation model is the degree of accuracy in representing the subassembly part shape. The grid based algorithm's main benefit was its flexibility and speed. This is because the simulation model will require placements of multiple days', even multiple months' worth of plates, and the plates' shapes do not need to be represented to a great accuracy. However, for the algorithm for generating a detailed subassembly arrangement layout for a specific point in time, the part shape needs to be represented as accurately as possible and so a vector based representation of the shape was used.

Also, there have been no further optimization in the order of placement and the rotation angle of each of the plates in the grid based algorithm. In order to further optimize the order of placement and the rotation angle, genetic algorithm was implemented to meta-heuristically find a near optimal solution in the space of placement order and placement rotation angle. Because the algorithm makes many searches within the possible combination space, in order to minimize computation time, candidate location for placement must be searched as quickly as possible. This study opted for using No-Fit-Polygon to determine candidate locations.

The subassembly workshop has several rules and conditions for placement of the plates to make production work more manageable. These rules, illustrated in Fig. 18 need to be applied to the algorithm in order to create a layout of sufficient quality able to be used in the field. First, the shape of the work area in the algorithm needs to be customizable. This is because the work area may already contain work-in-process parts and the area containing these parts must be excluded from the work area inputted into the algorithm. Also, subassembly parts set to be assembled into the same midassembly must be placed in close proximity to each other. Finally, the port and starboard parts of the lot must be separated on the workshop floor.

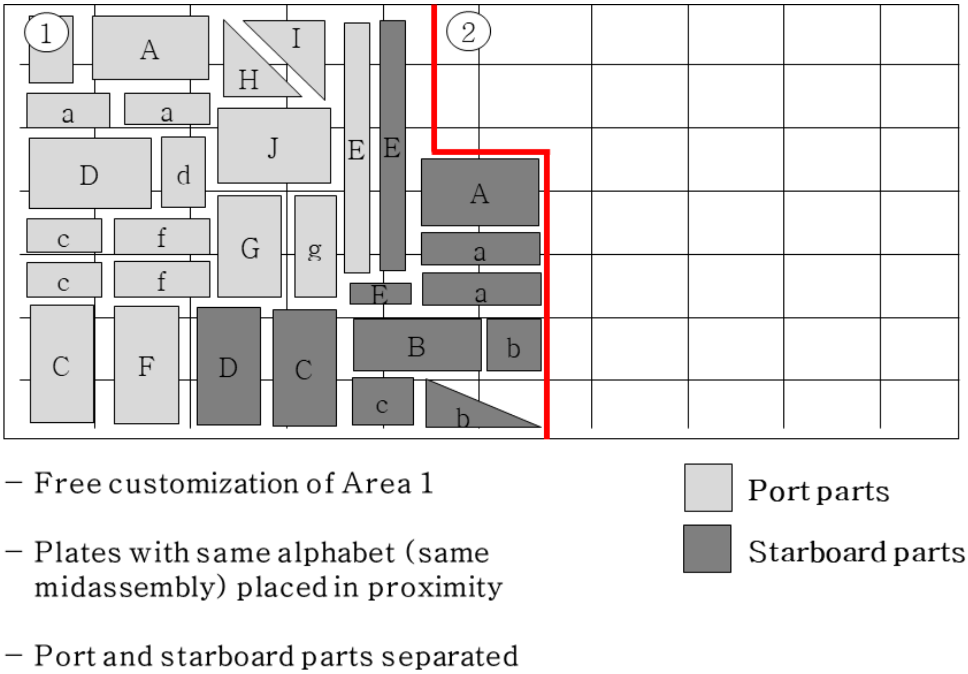


Fig. 18 Subassembly production rules and constraints

In this study, a system was developed to create a detailed arrangement layout of subassembly base plates for specific points in time. This system does not create a layout for a period of time, instead it takes as inputs a workshop floor shape and the subassembly base plate shapes to be placed and places them as efficiently as possible for a single point in time.

4.2 Algorithm structure and details

Two evaluation criteria was used in the algorithm to produce two different methods of optimization as illustrated in Fig. 19. When attempting to find the position of a shape, the first method attempts to minimize the length of the furthest right end point of the shapes. The second method attempts to minimize the area of the bounding box of the shapes. The layout results from the two evaluation criteria will be discussed in further detail later.

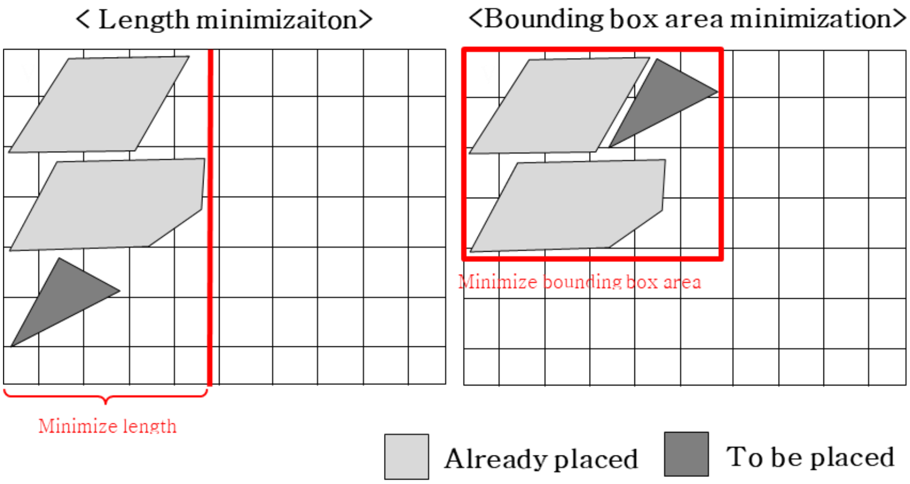


Fig. 19 Two evaluation criteria used in algorithm

As explained in the previous chapter, the subassembly process has several conditions on placing the plates. First, the plates that require midassembly need to be placed in a similar area. This is done to reduce handling time of plates that will be assembled together and also to reduce time of searching for the plates. Second, blocks in shipyards often come in symmetrical pairs for the port and starboard side of the ship. Because the symmetric blocks are joined together at the same time in the pre erection process, the subassembly of these blocks usually begin at the same time and enter the subassembly stage in the same lot. Therefore, within the same lot, the subassembly parts on the port side and the starboard side need to be separated into two separate areas. Third, the plates are placed with its long axis parallel to the y−axis of the workspace. This is a guideline to save space and keep the work area organized.

In order to accommodate the production rules and conditions, the ordering of the genetic algorithm's chromosome was changed. First, the rule of separating port and starboard parts into two distinct section of the work area was taken into account by sorting the part placement order chromosome by port and starboard. As illustrated in Fig. 20, it can be seen that after the initialization of the chromosome, the algorithm will sort the chromosome by port and starboard and during mutation, will not allow port and starboard sections of the chromosome to exchange positions. This ensures that port parts are always placed first in the work area. Because both the 'length minimization' and 'bounding box minimization' evaluation criteria both place the next part adjacent to previously placed parts, the port and starboard parts will be grouped into two separate areas once placement is complete.

In order to place parts of the same midassembly group close to each other, the part placement order in the chromosome was ordered by midassembly group after every mutation and crossing over. The order of the first occurrence of a midassembly group was maintained through the reordering. In Fig. 20, alphabet letters represent parts in the same midassembly group (upper case are the base plate of the midassembly and lower case are parts that will be installed on top of the base plate). From looking at the figure, it can be seen that after the switching of the positions of ‘a’ and ‘B’ part, the parts part of the A midassembly and B midassembly are reordered so that the midassembly group parts are adjacent to each other. As with the port/starboard grouping, by placing the midassembly parts right after one another, the placements will tend towards grouping the midassembly parts in a similar area.

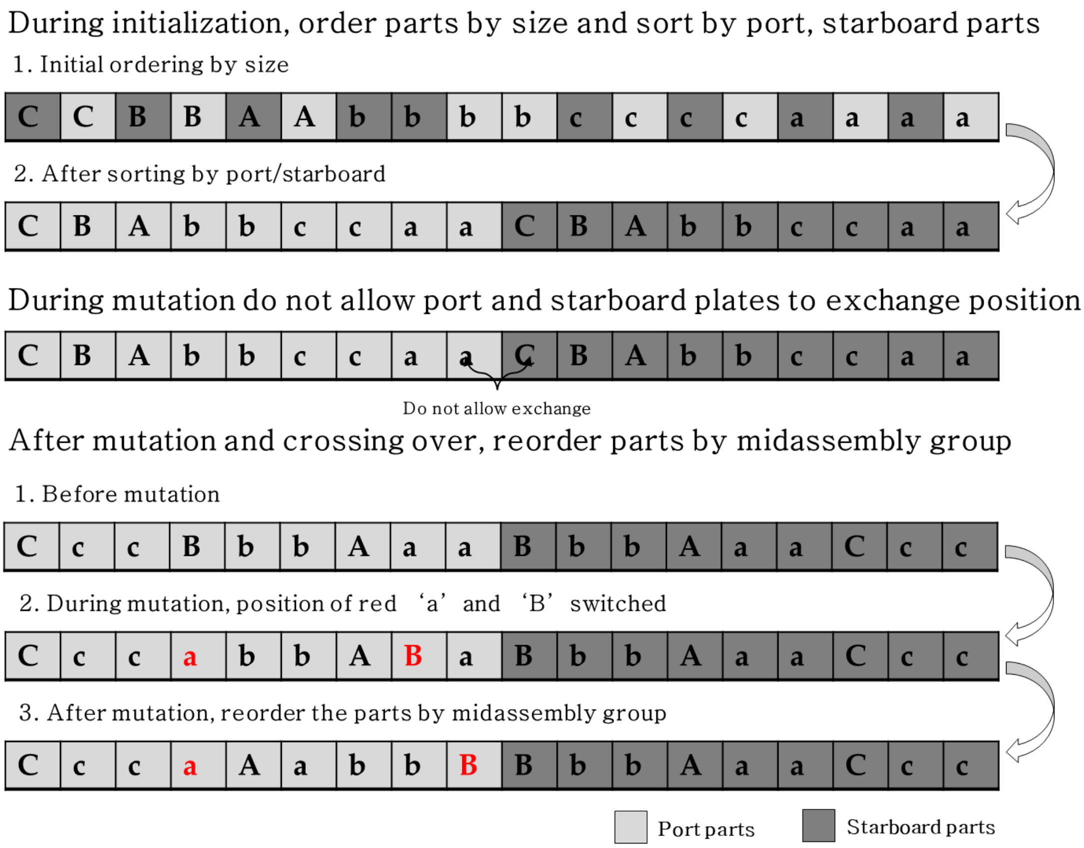


Fig. 20 Reordering of genetic algorithm chromosome

The production rule of keeping the long axis parallel to the y-axis of the workshop was implemented using PCA analysis of each of the shapes to find the principle axis of the shape. The major and minor axis and the angle of the shape was determined and the major axis of the shape was rotated so that it was parallel to the y−axis of the workspace.

As illustrated in Fig. 21, the algorithm calculates the position of the subassembly parts the following way. Once the plates for placement are selected, the plates are ordered by area, so that the largest plates are placed first. Then, the placement order of the plates are reordered by port/starboard and midassembly group as described previously. Then the first plate is placed in the bottom left corner. Before placing each subsequent plates, the No Fit Polygon between the already placed parts and to be placed part are calculated. Then the intersections between the No−Fit−Polygon are calculated as candidate positions. The positions that lie in other No−Fit−Polygons are discarded. Then for each of the candidate positions, an evaluation value is calculated. The two possible evaluation criteria are 'length minimization' and 'bounding box area minimization' as explained previously. The position with the best selected evaluated criteria are selected and the position of the part fixed. Then the same process is repeated for each subsequent parts until all parts are placed.

Genetic algorithm creates multiple combinations of the part placement ordering and the rotation value for each part and finds meta−heuristically close to optimal combination which minimizes either of the two evaluation criteria. The two chromosomes with the best fitness values are picked from the population and crossed over. Single point crossover is performed to create two child chromosomes. The child chromosomes are mutated. For mutation, a uniform mutation is performed, whereby with a random likelihood each plate has a random chance of being swapped in location with the next plate. Also each plate has a random chance of changing its rotation angle by a fixed degree. After each crossing over and mutation, the part placement order is reordered by port/starboard and midassembly group. Finally, the child chromosomes replace the two least fit chromosomes in the population. This process is repeated until the user decides that a sufficiently good arrangement layout has been created and terminates the algorithm.

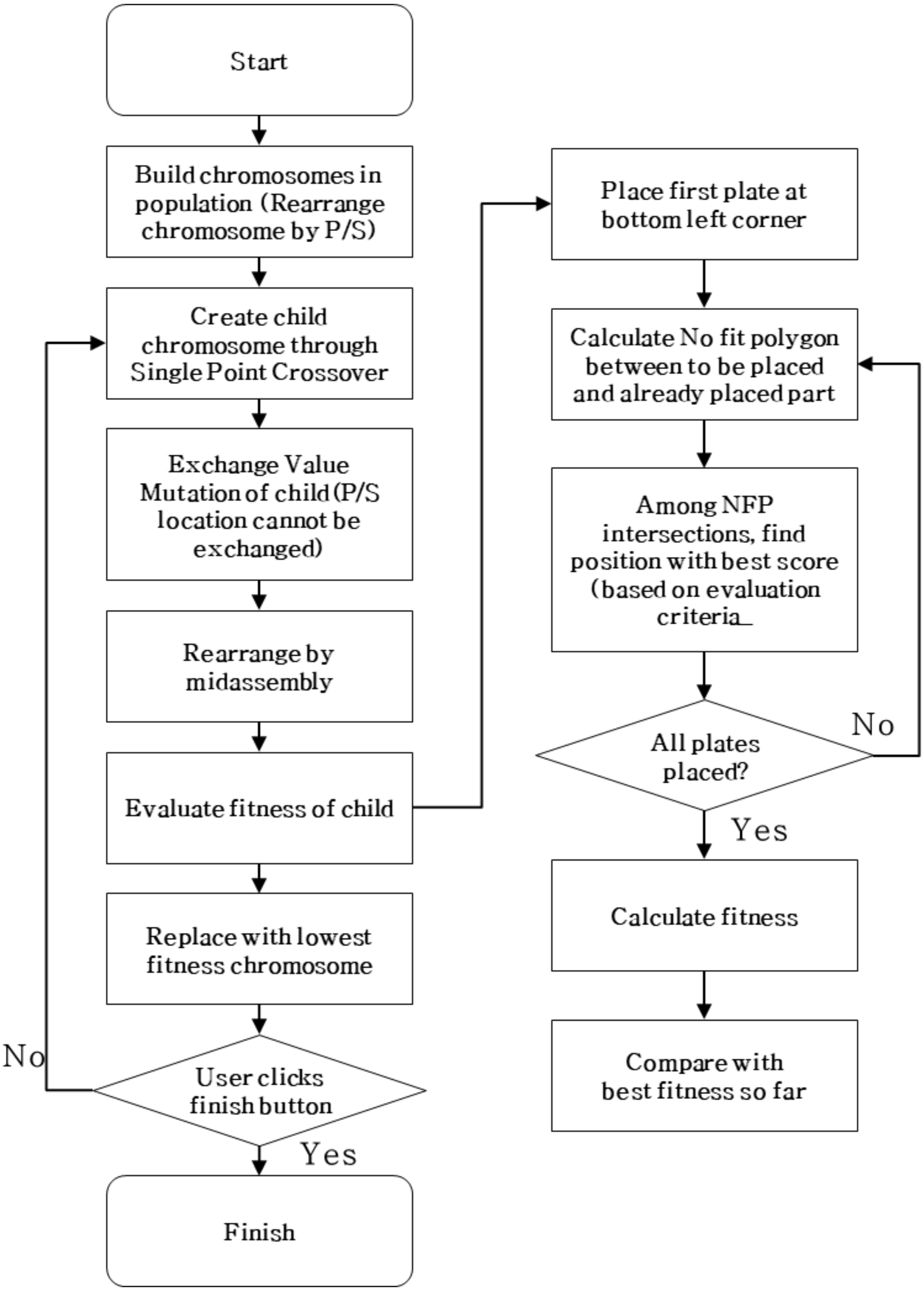


Fig. 21 Detailed subassembly part arrangement algorithm flowchart

4.3 Detailed arrangement layout system

In this section, the development of the system implementing the algorithm discussed in the previous section will be discussed. The design choices and functions implemented to increase usability and take into account subassembly production rules will be discussed.

First, the user had to be able to freely shape the workshop floor shape. This is because the workshop floor contains plates that enter and leave the workshop at different days. So in a certain day, certain sections of the workspace may be occupied by plates already placed. In order for the foreman to create a layout for the free area, the work area shape needed to be able to be adjusted. The user needed to be able to freely draw only the section of the workspace that can accommodate new plates.

Within the program, the user brings up the entire workshop floor shape. Then the user can manipulate the workshop floor shape as the user desires in two ways. First the user can create rectangular shapes by clicking at two points on the workshop shape. The two points will be used as ends of the newly created rectangular workshop area. Another way is to draw a polygon in the workshop shape by clicking the points of the desired end points of a polygon. When the points are connected, the resulting shape will be used as the workshop area.

By the nature of the genetic algorithm, progressively better arrangement layouts will be created and the program captures the history of the layouts created so far so that the user has the option of choosing which layout to select for final confirmation. In addition, the distance between plates can be adjusted. Finally, multiple lots can be placed at once and the lots can either be differentiated in area or placed together.

4.4 Algorithm evaluation and analysis

In order to determine the performance of the algorithm and explore which evaluation criteria resulted in a better arrangement layout, three subassembly lots' arrangement layout was created.

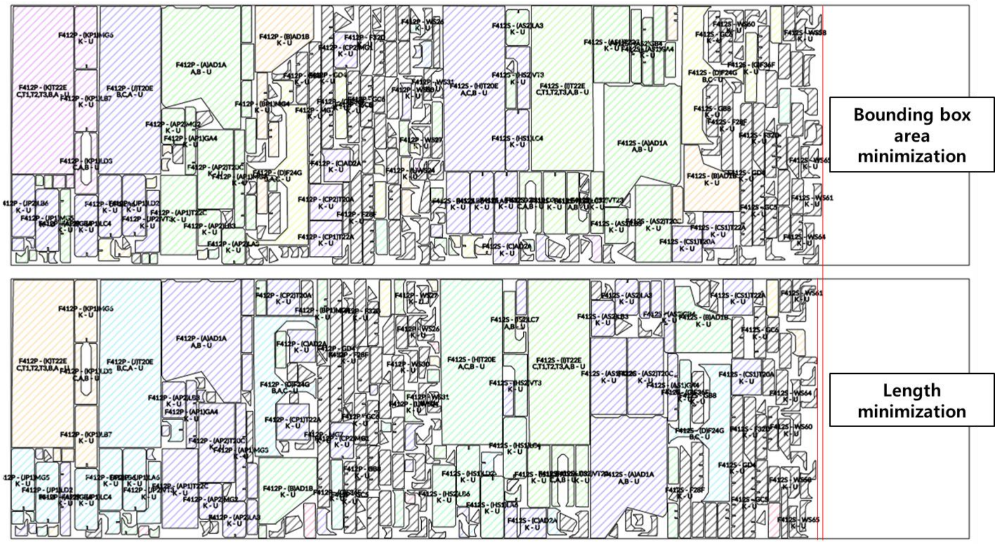
The three subassembly lots' arrangement was created ten times for each algorithm evaluation criteria and their results averaged and presented in Table 3. The performance evaluation criteria was the percentage of usable empty area in the work area. Usable empty area was defined as the rectangular area between the vertical edge positioned by the right most end of the placed parts and the end of the work area. Usable area is an important criteria in the subassembly workshop because that is the amount of area determined by the foreman that can be used for placing a different subassembly lot on the shop floor. The total area of the work area was 1335.7 m^2.

As one can see from Table 3 and Fig. 22, the length minimization criteria outperforms bounding box area minimization criteria by 0.4%~0.9%. This result can be utilized by the production manager to preferably use length minimization evaluation criteria when creating a detailed subassembly arrangement layout with the goal of maximizing leftover usable area in the workshop.

Lot	Total part area	Length minimization	Bounding box area minimization
F** Lot	1,064.0 m^2	15.8 % usable area left	15.3% usable area left
E** Lot	1,090.3 m^2	11.7% usable area left	10.8% usable area left
E1* Lot	266.6 m^2	79.4% usable area left	79.0% usable area left

Table 3 Algorithm performance result of the evaluation criteria

Lot	Total part area	Length minimization	Bounding box area minimization
F** Lot	1,064.0 m^2	15.8 % usable area left	15.3% usable area left



Lot	Total part area	Length minimization	Bounding box area minimization
E** Lot	1,090.3 m^2	11.7% usable area left	10.8% usable area left

Lot	Total part area	Length minimization	Bounding box area minimization
E1* Lot	266.6 m^2	79.4% usable area left	79.0% usable area left

Fig. 22 Examples of the arrangement layout

Chapter 5. Conclusion

In this study, spatial arrangement planning in shipbuilding's subassembly process was examined, and methods of analyzing spatial resources using spatial arrangement planning algorithms were explored. A methodology of analyzing the space resource and refining the production schedule was presented.

This study was motivated by the difficulty in the subassembly process of validating the feasibility and predicting resource capacity problems in the subassembly production schedule. There was a difficulty in accurately predicting the amount of space resource required for the production schedule at hand. This study approached this problem through the use of discrete event simulation with spatial arrangement algorithm to simulate the subassembly production. The production schedule was analyzed using the simulation model. The simulation model calculated the individual subassembly part's start and finish date by taking into account the available manpower resource. The simulation model then calculated each subassembly part's position on the workshop floor. The result of the simulation was used to analyze whether delays occurred due to a limit in space and/or manpower resources. The simulation model then can be used to examine possible solutions to problems in the production schedule.

This study was also motivated by the difficulty in the workshop floor of placing and arranging subassembly parts on the workshop floor efficiently. Because of the irregular shapes of the subassembly parts, space was sometimes not used efficiently and estimations of the amount of space required for a given subassembly lot was not accurate. This study approached this problem though developing an algorithm to create a detailed subassembly part arrangement layout. The various subassembly production rules and conditions were taken into account by controlling the order of placement in the chromosome of the genetic algorithm. The algorithm's performance was evaluated through creating an arrangement layout of three different subassembly lots and the two evaluation criteria of the algorithm was compared.

By utilizing the proposed methodology in this study, subassembly production can be better controlled through the creation of more accurate production schedules. Also, space resource can be more efficiently utilized.

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초 록

조선소의 소조립 공정에서 공간 자원은 생산 능력을 결정하는 주요 자원이다. 공간 자원을 효율적으로 관리하기 위해서는 생산 계획 검토 단계에서 소조립품 배치 위치 및 공간 활용에 대한 분석이 필요하다. 본 연구에서는 이산사건 시뮬레이션 모델링 및 공간 배치 알고리즘에 기반한 소조립 공간 자원 활용 계획을 분석하는 방법론을 제안한다. 시뮬레이션 모델과 모델 내 탑재되어 있는 소조립 계획 및 공간 배치 모듈을 활용하여 생산 계획 기간동안의 생산성 및 계획준수율에 공간 자원이 미치는 영향을 분석할 수 있다. 이를 통해 생산 계획의 타당성을 검증하고 개선 방안 도출에 도움이 될 수 있다. 다음으로 유전알고리즘에 기반한 소조립 주판 배치 레이아웃 생성 알고리즘 및 방법론을 제안한다. 소조립 주판 배치 레이아웃 생성 알고리즘을 통해 소조립 작업장 공간 활용률을 높일 수 있으며 작업에 필요한 공간을 정확하게 예측할 수 있다. 마지막으로 소조립 생산 사례를 시뮬레이션 모델로 분석하고 소조립 주판 배치 레이아웃 생성 알고리즘의 성능을 평가하였다.

주요어 :

공간 배치
이산사건 시뮬레이션
소조립
유전알고리즘

학　번 : 2018-26997