Master of Science in Engineering

Work Activity Relation Approach of Modular Factory Production Management Using Dependency Structure Matrix (DSM)

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Abstract

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A modular system uses a construction method which the structure is manufactured in factories and assembled on site. In particular, conducting most of manufacturing process at the factory makes it possible to obtain consistent quality of the materials and finish the project within the time constraint. Moreover, high factory production rate leads to a decrease of field production rate; and the decrease in field working hours would drive down the task difficulty which is affected by bad external environmental factors. Hence, optimized factory production system is essential to maximize these system advantages and smooth production flow by mass production of modular

construction. This paper aims to suggest optimized construction process in a factory production stage using the DSM (Dependency Structure Matrix) which considers construction information flow among activities. For this, it is necessary to identify modular as-is process and activities and attempt to derive modular unit process optimization. Then, to validate effectiveness of this study, this methodology is applied to the real modular factory. As a result, it reduced about 50% of information transfer compared to the original. Also, as an one way construction flow, it reduced the possibility of production delay and rework. Thus, this paper is expected to produce activity information flow smoothly during the factory production stage and reduce rework.

Keywords: Modular System, Prefabricated Construction, DSM (Dependency Structure Matrix), Modularization

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

This chapter presents the background of the research in modular construction and identifies the problem of production process in a modular factory. Then, it introduces the purpose of the research to enhance the current process. Finally, the scope and research process are discussed.

1.1 Research Background and Objective

The concept of building production based on factory was suggested by Peter Behren, and Richard Neutra, etc. during the 1920s. Then, in the late 1940s after World War II, it was first used in Europe for the fast post-war reconstruction. The modular construction method is applied to various types of buildings such as military barracks, schools, offices and residences. It has many useful advantages such as reduction of overall project schedules, consistent quality, extensity of space, cost savings, increased onsite safety performance, reusability and so on (Mullens 2011, Smith 2010).

Recently, because of the explosive population growth and workforce reduction, modular construction is used in the general building market in order to increase construction productivity and cost efficiency, which in return rapidly grew developed countries (Mullens 2011). Majority of the construction work for modular construction method occurs in the modular factory except for groundwork and on-site assembly (Carlson 1991). This makes a critical difference between modular and traditional construction methods. Construction work for traditional construction methods, such as RC

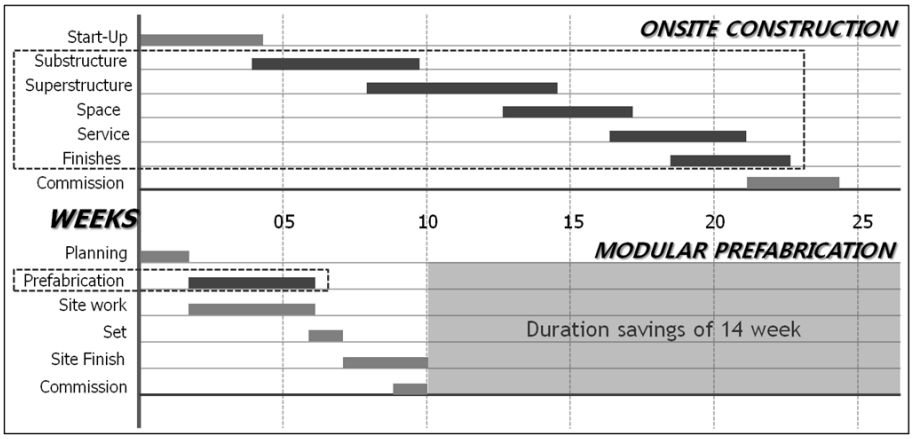


Figure 1-1. Construction Process Comparison (Ryan 2010)

and Steel Structure, occurs on-site; however, the modular method preceeds most of the construction works in modular factory except for groundwork and on-site assembly.

Fabrication system of the modular construction can reduce construction duration dramatically because factory mass production and work phase overlapping. Figure 1-1 shows the comparison of construction processes of modular and traditional construction. Unlike site based traditional construction, ground work can preced during the prefabrication of the module unit. Furthermore, modular building construction work is not affected by external factors; risk from the environment can be significantly reduced (Manufactured Housing Institute 2013).

For example, there can be construction delays due to bad weather, worker safety problem, increase of work difficulty, and so forth. However, modular construction method has production efficiency advantages due to factory mass production offered by the line production. Thus, the evaluation of the production system efficiency in the factory is essential to maximize the

efficiency of factory production and meet the growing demand of market for modular factory. Hence, productivity improvement of modular unit production system has been a great concern to manufacturers and production managers (Abu hamad 2003). However, many typical modular factories fail to produce at maximum capacity and increase productivity (Mullens 2011). In general, two strategies have been used for industrializing construction productivity which are “product approach” and “process approach” (Yu 2011). “Product approach” aims at minimizing on-site construction activities by turning building into products that can be manufactured in the factory environment, while the “process approach” focuses on applying a manufacturing management model to the current construction process (Yu 2011).

However, construction industry is labor-intensive and modular system is also based on construction work (Senghore 2004). Furthermore, the entire process of modular construction takes a short time compared to on-site based construction. Moreover, fabrication process of modular factory consisted of various types, such as architecture, facilities, electrical and a number of activities that increased the complexity of the overall process.

Due to this feature, bottleneck effect occurrence of the line caused production delay. Bottleneck effect is a phenomenon where any process slowdowns caused by the limitation of the production capacity (Goldratt 1992). In other words, if increasing the amount of work per station more than the production time allocated to each station, the queue for work standby will be longer. Therefore, it is necessary to allocate the appropriate spare time (or buffer time) between the production cycle time for a smooth flow of module

production. Once production delay of modules due to the bottleneck occurs, effort to solve this problem causes secondary problem such as waste of labor resource and changes of the station in the production process. To solve this production problem, modularization production process for the improvement of modular factory was suggested in this study. This will result in a production flow that can decrease the complexity of overall process of modular production by modularization of the work activities and rearrangement of the work activity for the sequential work flow. Activities will be rearranged and modularization will be performed based on work precedence information. For this, DSM (Dependency Structure Matrix) methodology was used to optimize the activity information exchange. Then, to apply modularization production method derived from the DSM methodology to modular factory production, framework for the factory was suggested. Using this framework, factory production layout was suggested and case study was performed on a real modular factory in South Korea to verify the utility of the suggested method.

This paper, therefore, aims to analyze the as-is process of the Korean modular factory. It also used derived activities which are divided into main-sub processes and suggests process management method in the factory production stage of modular construction using the DSM (Dependency Structure Matrix).

1.2 Research Scope, Method and Process

This paper will focus on a bachelor officer's quarters in the factory production stage.

In this paper the DSM methodology is used in modeling the relationships of each system component. DSM displays the relationships between the system components in a compact, visual and analytically advantageous format (Tyson R. et al. 2001). It can represent complicated work algorithm more simply and visually. Therefore, it is suitable for analyzing and optimizing complex activity of modular production that performs in a day to a week.

The research process is as follows:

(1) Identify problem of current modular factory production process by factory inspection and literature.

(2) Review the research trends of the modular factory production management system and approach method.

(3) Propose the DSM modeling process and framework for factory production management based on the work flow using DSM.

(4) Implement a case study of K modular factory in South Korea to evaluate the applicability and effectiveness.

(5) Suggest effectiveness of work related production management and its activeness.

This process for the overall research structure is exhibited in Figure 1-2.

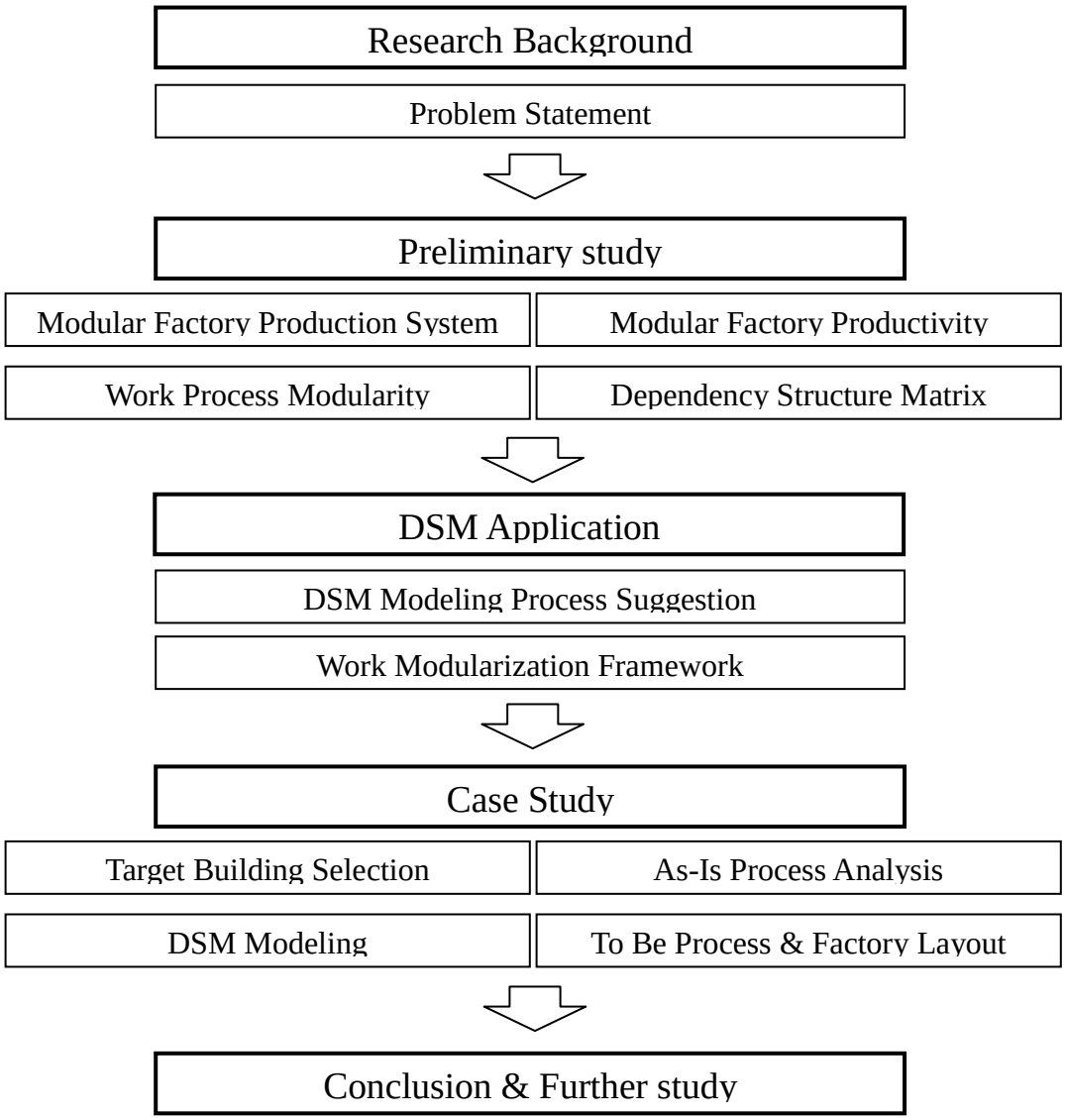


Figure 1-2. Research Process

Chapter 2. Preliminary Research

This chapter reviews the previous research of modular factory production system, modular factory productivity, work process modularization and DSM methodology. The limitations of the earlier research in modular factory management are found by reviewing the literature. Then improved method to overcome the problems is introduced. For this, process modularization of the work activities is introduced based on work information relationship. Finally, DSM methodology demonstrated for work process flow improvement and modularization is introduced.

2.1 Modular Factory Fabrication System

As described above, since at least more than half of the entire construction process of the modular construction proceed in the factory, many preceding research focuses on the factory production process and its productivity. Hammad (2001) researched that utilizes a simulation method; implement the process plan to predict the production of units daily through making production process by including all the stations of the assembly line. It presented a decision-making tool to factory manager for effective unit production management by simulating the unit production capacity and predicting the high risky section of the bottleneck occurrence in the line. However, this research presents simulation method to predict production delay work or station for factory manager. Therefore, the limitation is

omitting the production improvement solution and flow management method.

To overcome the limitation of the previous research and improve the modular factory production flow, many studies investigated the quantitative and qualitative approaches to evaluate an efficient process. Mehrotra et al (2005) considers the production disrupt factor as ineffective facility layout design. Thus, they suggest layout design steps for the qualitative analysis of the facility design based on space requirements and proximity parameters. Also, Banerjee et al (2006) presents the process of quantitative modeling based on mathematical approach and evaluation of the facility layout alternatives of a modular factory based on the material flow aspect. And Hammad (2008) also evaluates the production system efficiency; propose decision support system to assist the user in selecting an efficient layout design matching specified production capacity and market requirements in their follow up study. These physical approach based on factory line have contributed significantly to the efficient production of modular process, enlarging factory capacity. However, these systemic approaches still have the potential threat of the production delay from work process complexity and low labor productivity from factory line production. To cope with these potential threats and integral factory management, some researchers introduced the lean production system from automobile industry to modular factory management. Yu (2011) implements lean tools such as 5S (sort, set in order, shine, standardize, sustain), standardized work, takt time planning, variation management, and Value Stream Map (VSM) in building components

prefabrication and established the foundation for expanding lean practices to prefabrication area for productivity increase. Mullens (2011) develop modular factory design process for better work process and production flow based on lean construction principles for quick response market demand. Also, Moghadam (2012) proposes an integrated model that applies both BIM and lean on a modular construction manufacturing (MCM) process and gains the benefits of both concepts. For this, Value Stream Map (VSM) of the factory is generated based on the components' schedule through a proposed Integrated Process Improvement (IPI) method using a set of mix lean principles to reduce waste over a broad range of factory activities.

In an effort to address modular factory production improvement, this research proposes modularization production method for the improvement of modular factory production flow based on work activity relationship. It is more powerful and efficient management method than the previous research since it is a simple and easy applying to the factory process.

2.2 Productivity Interrupt Factors of Modular Production

Modular construction method precedes most of the construction work in modular factory except for groundwork and this makes a critical difference between modular and traditional construction methods with on-site based. Also, modular production process is based on the line production system, similar to that of the manufacturing industry. Moreover, entire process of modular construction takes one or two days per each unit, and consists of different types. Line production can become a threat leading to the decrease of the factory productivity.

2.2.1 Bottleneck Effect

Immediately influencing the productivity of the factory process is the production delay caused by bottleneck effect that is the characteristic of the factory line production system. Bottleneck effect can be defined as a situation where a process slows because of a limitation of system production capacity (Goldratt1992). In other words, if the workload amount increases for a station, the queue for waiting work will be longer. Therefore, appropriate allocation of the production time and buffer time is very important for a smooth production flow.

For example, if production time allocation is longer than workload, frequency of bottleneck occurrence can be reduced, but labor productivity and production amount in a day also decreases because of the limitation of daily

working time. On the other hand, if production time allocation is shorter then workload, frequency of bottleneck effect occurrence can increase; however, bottleneck effect from production delay can occur frequently. When bottleneck effect occurs in one part of the production process once, other work process stops until the bottleneck disappears. It directly causes loss of labor and factory productivity and can cause secondary problems such as work process change, work loss and factory congestion.

2.2.2 Rework

In construction projects, rework means a series of work to be done again by removing the work that is already done which is a critical factor of work delay and product quality (Rogge et al, 2001).

In case of the field-based construction, there is enough time to find rework activities and recover the lost process. However, line production based modular construction has a big impact to production flow to cover rework activities because many activities are performed in a short time compared to on-site construction. Moreover, during line producing, a problem in one station can affect the entire work. Therefore, in order to prevent occurrence of rework, it is important to reduce the complexity of work activity and mutually related work that has high possibility of rework occurrence have to be managed together.

2.2.3 Work Congestion

The building construction is characterized as working in a limited space and determined by the site area of buildings. Thus, when working inside a building, the appropriate number of workers and material input can affect the productivity and working environment. In the case of modular construction method, the size of each unit or plant is very limited, that over certain number of worker and material input can decrease the productivity rapidly. Furthermore, the advantage of modular construction is that it is not affected by the outside condition while working. However, when repeating the work in a limited space, congestion of the work, space and traffic can increase smoothly from worker, material and equipment. In order to prevent this problem, there is a need to reduce the unnecessary waste of space and work.

2.3 Work Activity Modularization

In the last decade, the concept of modularization has caught the interest of engineers, management researchers and corporate strategists in a number of industries such as automobile, information technology, and manufacturing (Baldwin and Clark 2004). Module is commonly defined as an independent chunk that is highly coupled within but only loosely coupled to the rest of the system (Holtta-Otto and Weck 2007). Modularization has many advantages from an engineering perspective, such as to make complexity manageable through simplification of the object; to accommodate process uncertainty; and to make possible tested and evaluated independently (Baldwin and Clark 2004, Frenken and Mendritzki 2011).

However, at the same time, higher degree of modularity can decrease integrality of the whole system (Holtta-Otto and Weck 2007). Integrality is the opposite concept of modularity that means of pertaining to or belonging as a part of the whole; constituent or component.

For this reason, regardless of the many benefits of modularization, fully modularization may not always be achievable (Whitney 2004). In case of

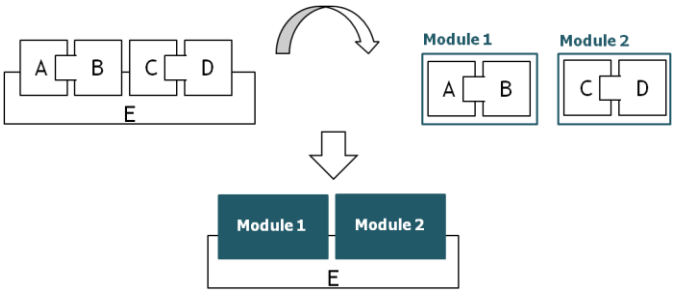


Figure 2-1. Module and Modularization

highly connected among integral activities, integrality of the whole system better important then part of modularity. Therefore, important point to modularize of the complex activities is how to modulate the closely related work and at the same time, reduce the complexity of the entire work system by considering the integrality of the whole process.

In respect to these conditions, Dependency Structure Matrix is a very useful method because its analytical feature for decomposition of the relation of activities and integrate optimization of the whole process. Also, to visualize patterns of modularity in those patterns, Dependency Structure Matrix (DSM) is very helpful because of partitioning & clustering algorithm.

Also, DSM tool can express dependencies and interdependencies of activities in the modules (Figure 2-2).

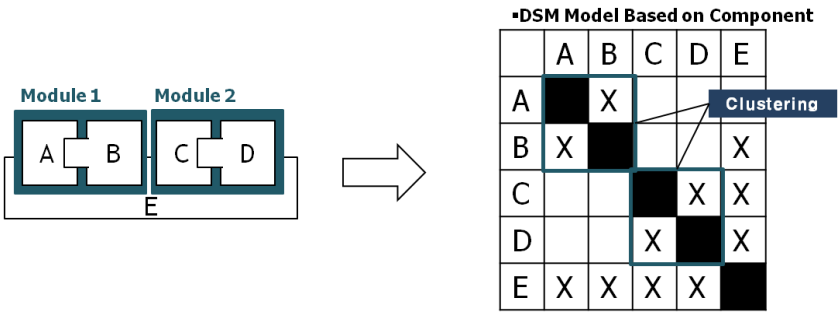


Figure 2-2. Module Expression by Dependency Structure Matrix

2.4 Dependency Structure Matrix (DSM)

There are many construction process management tools and recently network type tool such as CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique) is widely used in the construction project.

These network schedule optimizing tools focused on sequence relationship of the activities and work time to estimate whole time duration of the project. However, such methods difficult in the covering mutual information exchange among the activities that has a high possibility of rework occurrence in advance. In addition, as relationship between the activities become more complex, process identification becomes more difficult and estimating construction duration loses its reliability (Jang 2009). Construction work has various types of work and many activities. In the case of modular construction, many complex activities that are mutually related are conducted in a short period of time. Therefore, a simpler and visually clear work management method that can express mutual information exchange is needed. Hence, DSM methodology is very suitable in order to solve this problem.

From the survey of tools used to model information flow dependencies and sequences, DSM is considered to be both powerful and flexible tool for construction management and implementation (Yassine et al 1999; Kusiak and Wang 1993). DSM representation methodology was developed more than 30 years ago, since then it was developed by a research group of MIT, Illinois, and Harvard University to analyze the complex systems. DSM is a project modeling tool which represents the relationships among the project tasks in a

matrix structure by its dependency relationship (McCord 1993). DSM is easy to visualize complex process and represent relationships of tasks as dependent, independent and interdependent tasks. It can identify the relationship of activities by breaking down the activities and displaying the flow of information more effectively in the matrix (Park et al 2012). A major advantage of the matrix representation over other tools lies in its compactness and ability to provide a systematic mapping among the elements, which are easy to read regardless of its size (Maheswari et al 2006). It is shown in Figure 2-3.

Previous studies to apply the DSM method on construction project, such as a design process management applying DSM which focuses on information flows between design activities and constructability knowledge (Park et al 2010), analyze the BIM design process at the introduction phase and find out the improvement design process using the DSM (Park et al 2012), optimize the lifting plan of tower crane (Jang 2009), are mainly used in the initial planning phase. However, in case of many preceding researches that utilized DSM only suggested advanced process method. Therefore in this study, not only was advanced process of modular production suggested but also its application methods to factory and management tool to the factory manager.

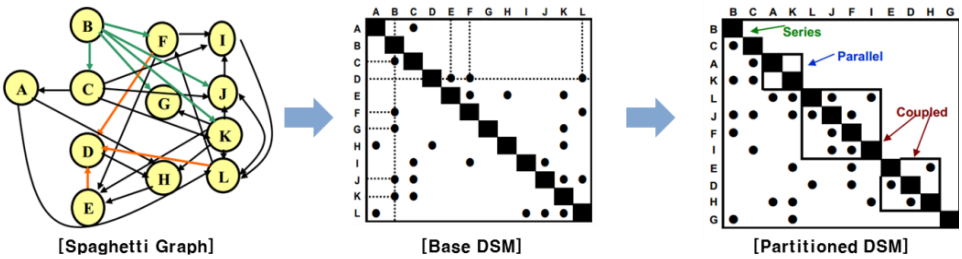


Figure 2-3. DSM Modeling Process (Yassine 2004)

2.4.1 Three Types of Activity Relationships

There are three types of activity relationships depending on the type of information exchange (Figure 2-4). These are parallel, sequential and coupled relationships.

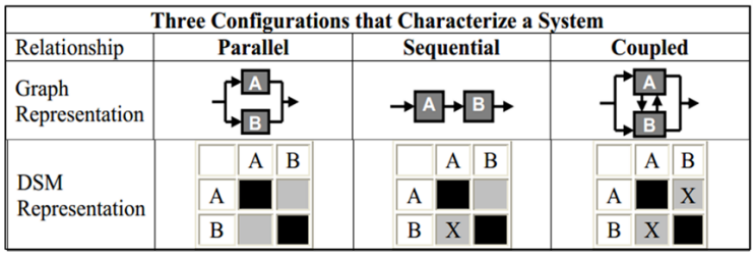


Figure 2-4. DSM Model Activities Relationship (Ali A.Yassine, 2004)

1)The Parallel Relationship

There are no informational relationships between activities. And it is expressed as empty in matrix.

2)The Sequential Relationship

There is one way information relationships; forward (A to B) or backward (B to A). And it expressed as ‘x’ sign in below of the diagonal square.

3)The Coupled Relationship

Coupled relationship is that each activity exchanges the information mutually. And it expressed as ‘x’ sign mutual square of the activities.

The original DSM model that created through the above relationship base of the activities developed for specific objective using Partitioning, Clustering,

Tearing Algorithm, and etc. (Browning 2001; dsmweb.org 2013).

In this study, in order to redistribute the activity sequence in a direction that minimizes the dependency of the work and modularization of the mutually related activities, mainly the Partitioning and Clustering Algorithm was used.

2.4.2 Partitioning and Clustering Algorithm

Partitioning algorithm is the series of process reordering of the DSM rows and columns such that the new DSM arrangement minimize containing any feedback marks that occur rework in the real process, thus transforming the DSM into an upper triangular form(Gebala and Eppinger 1991; demweb.org 2013). Figure 2-5 shows principle of the partitioning algorithm.

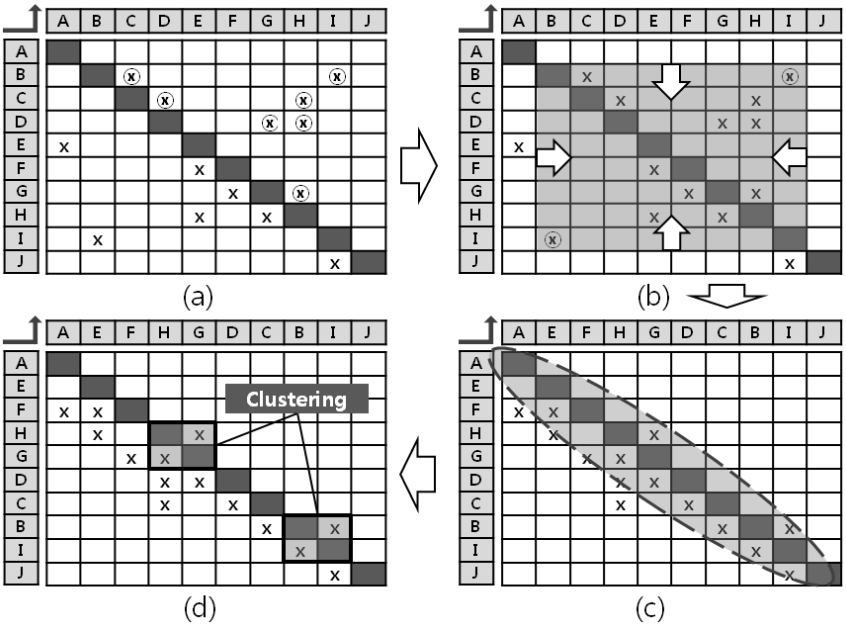


Figure 2-5. Partitioning & Clustering Algorithm

A “ⓧ” sign above the diagonal means a feed-back activities that repetitive work is needed to proceed to next work and “x” sign below the diagonal means a feed-forward activities that is sequential work process (Figure 2-5-a). If many activities located above the diagonal, whole system became very ineffective because repetitive activities and to minimize this repetitive activities, partitioning algorithm (Figure 2-5b) can be used. During partitioning algorithm process, each column and row of the matrix move towards each other to eliminate the repetitive work and approach the diagonal to secure continuity of the work (Figure 2-5c). However, for a process with complicated information flow, not all "x" signs above the diagonal may be removed after rearranging. Then these remaining correlate activities above the diagonal form a block. These series of the process called “Clustering Algorithm” Activities in the clustered block mutually exchange information that has high risk of rework occurrence; therefore it is needed for special management to handle. A series of partitioning and clustering algorithm are carried out to ensure work continuity and minimize the rework for the productivity of the system.

To conduct partitioning algorithm, “Path Searching”, “Powers of the Adjacency Matrix Method”, “The Reachability Matrix Method”, and “Triangularization Algorithm” are used to rearrange activities (www.dsmweb.org. 2013). In this study, the “Excel Macro for Partitioning and Simulation program (Figure 2-6)” based on The Reachability Matrix Method (Figure 2-7) with a multi-level hierarchical decomposition approach that is easy to calculate the complex matrix (Eppinger2000) was used.

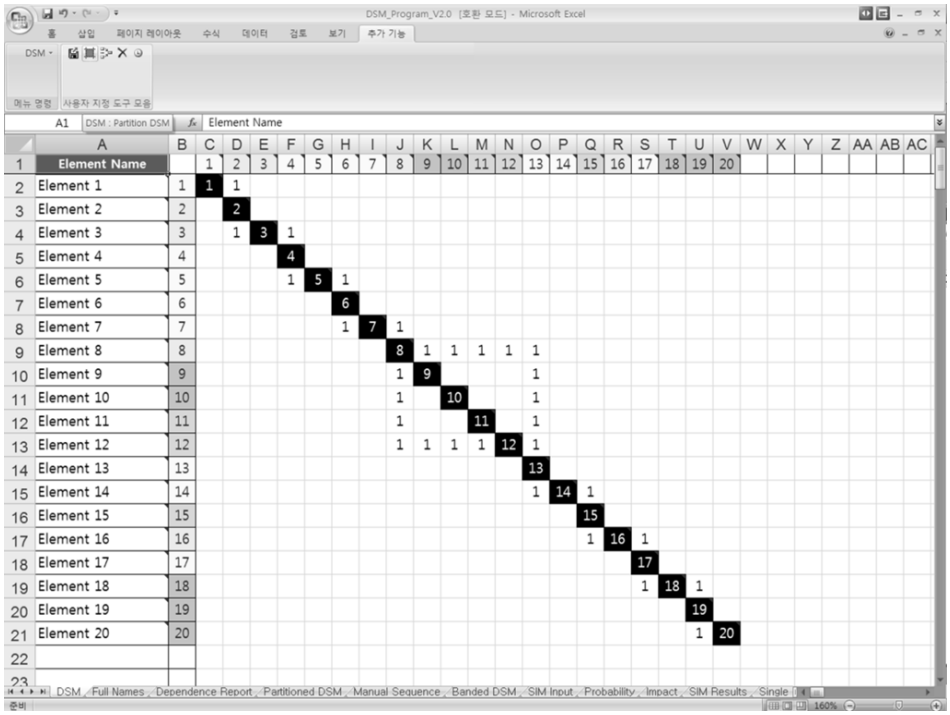


Figure 2-6. Excel Macro for Partitioning and Simulation program

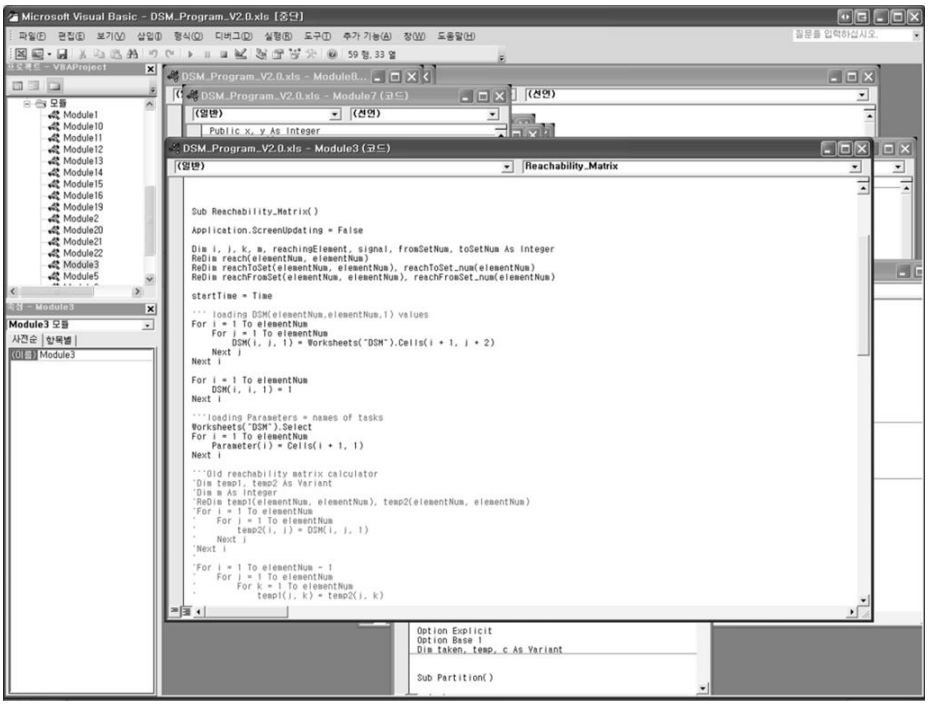


Figure 2-7. Reachability Matrix Method Source Code Example

2.4.3 DSM Taxonomy and Work Activity

Meanwhile, there are two main categories of DSMs: static and time-based (Figure 2-8). Static DSMs represent system elements existing simultaneously, such as components of a product architecture or groups in an organization. In time-based DSMs, the ordering of the rows and columns indicates a flow through time: upstream activities in a process precede downstream activities, and terms like “feedforward” and “feedback” become meaningful when referring to the interfaces (Browning 2001).

Therefore, DSM model can represent differently in the same product for the purpose (Figure 2-9). Hence, to apply DSM to certain system, researcher has to set the purpose and system definition exactly. Modular system is basically work intensive and time consuming process and as a result work relationship is very important unlike other manufacturing industry. Hence, the activity and time based DSM system was used to sort the factory work activities.

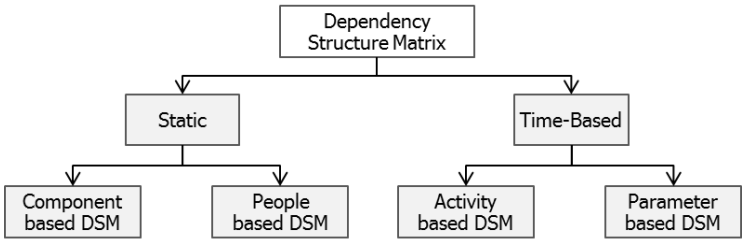
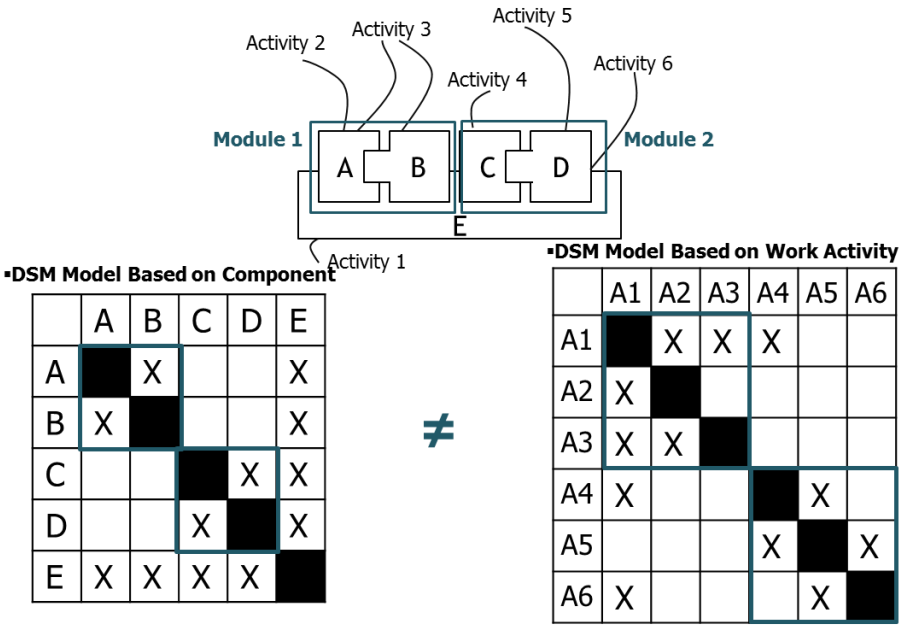


Figure 2-8. DSM Taxonomy (Browning 2001)



	A	B	C	D	E
A		X			X
B	X				X
C				X	X
D			X		X
E	X	X	X	X	

	A1	A2	A3	A4	A5	A6
A1		X	X	X		
A2	X					
A3	X	X				
A4	X				X	
A5				X		X
A6	X				X	

Figure 2-9. Component and Activity DSM Model Comparison

2.5 Summary

This chapter referenced the preliminary study of modular construction and research methodology. Many preceding researchers pay attention to factory production process and its productivity. However, many previous researches treat systemic approaches, but these still have the potential threat of the production delay from work process complexity and low labor productivity from factory line production. Modular construction is fundamentally a line production system similar to that of the manufacture industry. Such feature causes bottleneck effect occurrence, rework, work complexity and work congestion and so on that leads to production delay with loss of productivity.

Therefore, it is necessary to optimize the work process toward reducing complexity. For this, modularization production system can be a good solution. And Dependency Structure Matrix will be used for process improvement and modularization that can identify the relationship of activities through breaking down the activities and displaying the flow of information more effectively in the matrix.

Chapter 3. DSM Application to Modular Production

In this chapter, I suggest an activity modularization method to modular fabrication process that reflects characteristics of the module process to perform the many activities in a short time using DSM.

It is based on rearranging activity sequence according to partitioning and clustering algorithm that seeks for continuous information flow of the activities and creates a combined work activity module that modularize strongly relevant activities. Through these processes, the number of activities of the main line of modular factory is reduced which directly influences the work flow. And by creating combined module, complexity of factory work on the main line can decrease. Also through this process, a number of exchanges of work activity information can be reduced. Then to apply to modular factory layout these management processes, the modularization production framework for modular factory was suggested.

3.1 DSM Modeling Process for Modular Factory

In order to apply DSM methodology that is based on information exchange optimization to modular factory work process, it is necessary to select and sort work actives phase, and then analyze its workflow for system modeling. In this paper, a conceptual model to take advantage of by applying to a module factory actual DSM technique is presented.

As work information flow-based, process consisted of activity analysis module, DSM modeling module and process application module (Figure 3-1).

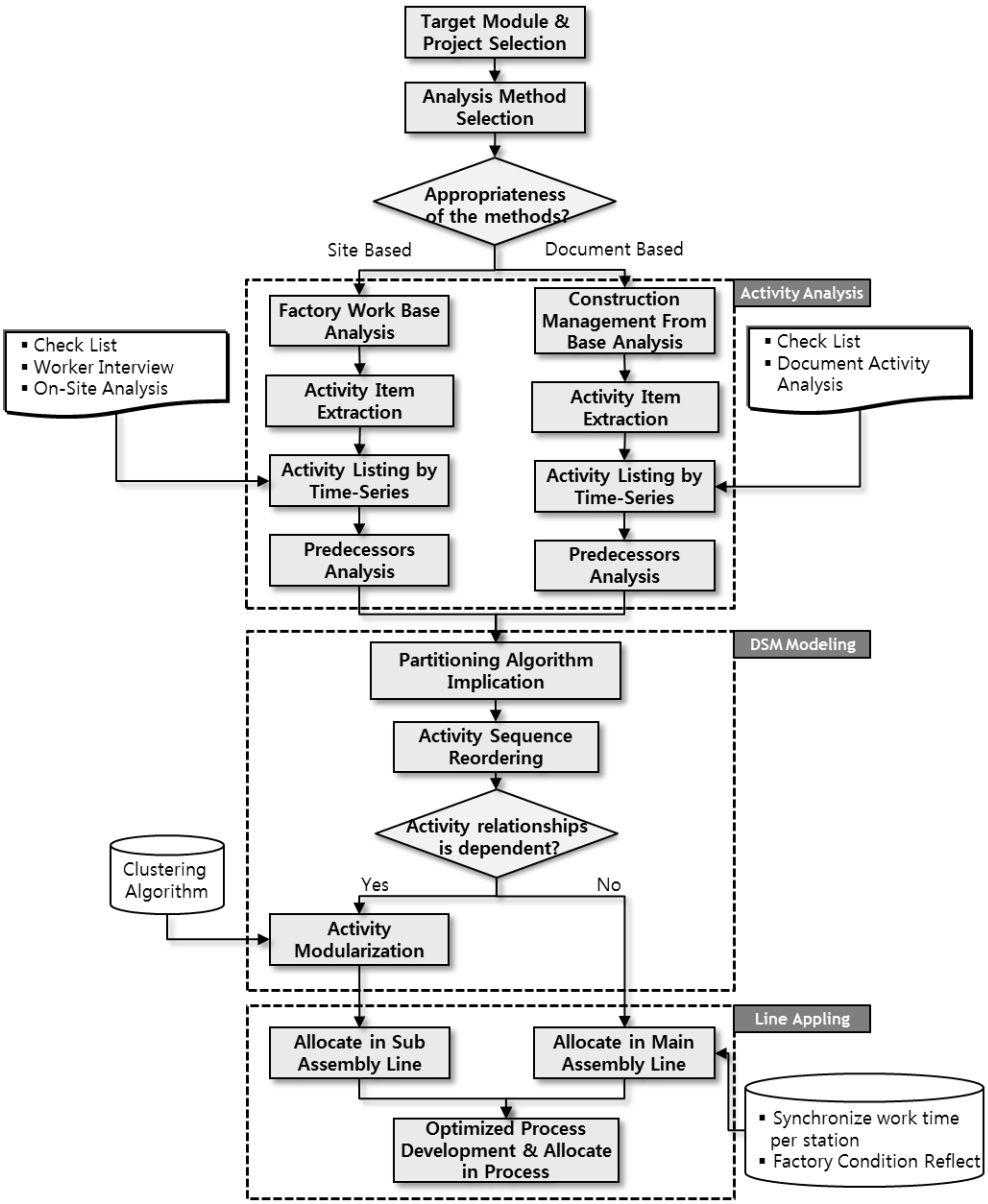


Figure 3-1. DSM Modeling Application Process for Modular Factory

3.1.1 Activity Analysis Module

First, select the module unit and target plant for process modularization of modular factory and determine the activity analysis method. Work activity is the detail level of work then the work content on the milestones, which means the series of workers act that occur in the workspace observed by researcher. As a field analysis, after observing workers acts, researcher record work type, details, and sequence on checklist step by step. This is conducted in the field in real-time in order to determine the entire activity sequence and work part of the module unit. If the infield analysis is difficult, it is possible to understand the relationship of the activity through worker interviews or milestone analysis.

3.1.2 DSM Modeling Module

In this stage, the DSM modeling implemented that using work activity which was extracted in the modular factory after analyzing its sequence and type of work. By applying the partitioning algorithm, work activities of the factory are reorganized to the optimal order of information transmission. In partitioning algorithm step, focus on independent & sequential relationship between activities and then analyze the whole process of the module production then minimize the feed-forward and rework activities through partitioning algorithm. After creating the new production sequence which applied partitioning, analyze the dependency among the activities, and then if

work interactions are strong among them, they are tied by the clustering algorithm.

3.1.3 Production Line Applying Module

Independent and sequential prone activities that are rearranged by partitioning algorithm are allocated at the main assembly line. Strongly correlated activities have a high-risk of re-work or production delay, therefore, modulated for allocating on sub assembly line. At this time, synchronizing work time per station for smooth production flow of the module unit is necessary.

3.2 Framework for Applying DSM

In order to apply the modularization production process to modular factory derived from DSM modeling based exchange of work information presented in Section 3.1, factory layout alteration has to be done as well as rearranging work activity module allocation. This must be applied by considering the mutual relation of the work activity such as construction, facility and electric production plan early stage in the project. For this series of process, factory space and production line information of the target factory is necessary for modularized process from DSM modeling applying. Therefore in this study, modularization production framework for modular factory suggested and that is shown Figure 3-2. The framework consists of input information, production rearrange processing and output. These framework steps consisted of some modules that operate independently but mutually related.

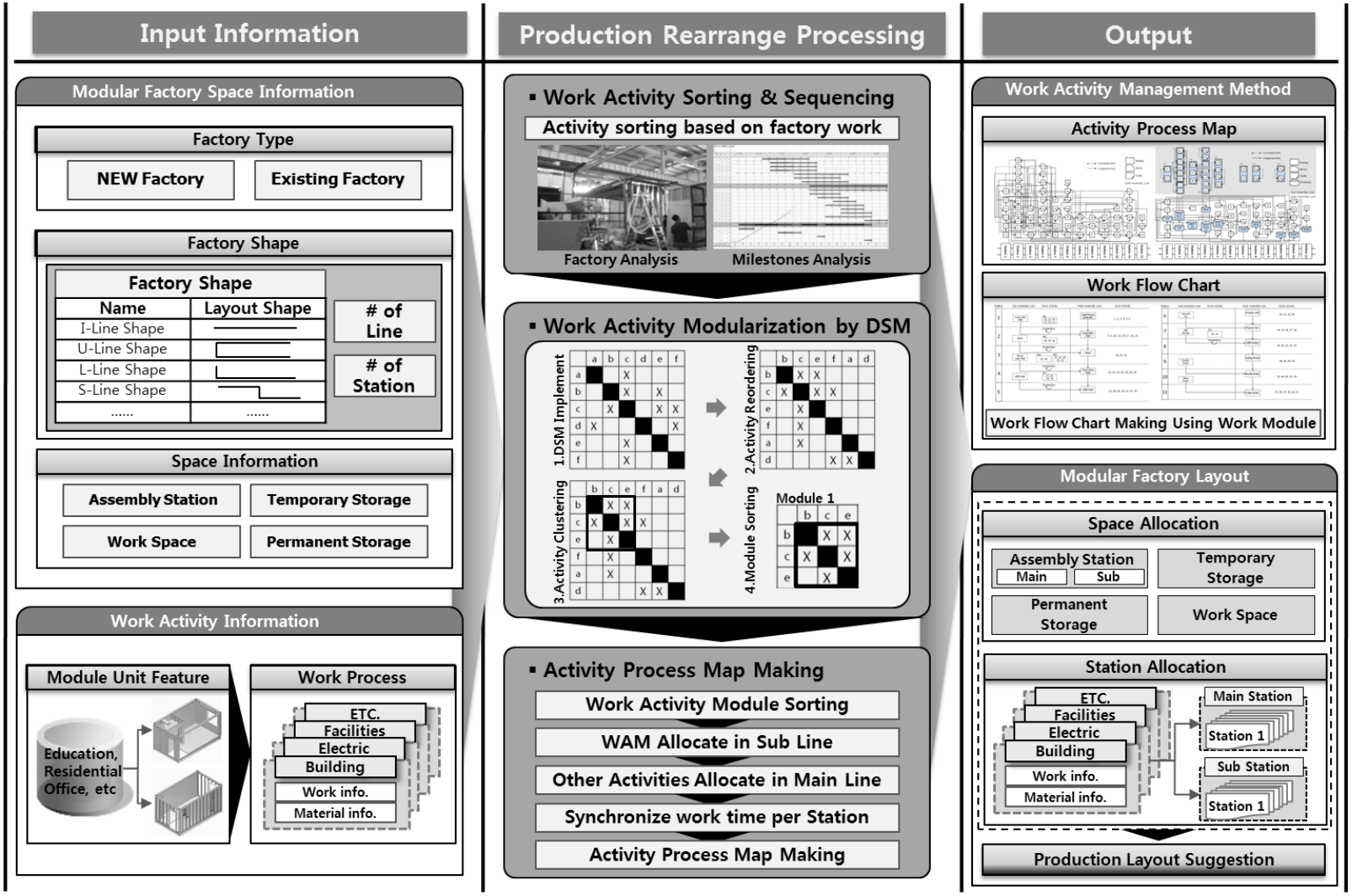


Figure 3-2. Modularization Production Framework for Modular Factory

3.2.1 Input Data Analysis

The input has information about existing factory space and work activity extracted from the target factory. In the modular factory space information module, analyze factory type (whether target factory is new or existing), factory shape (layout pattern, number of line and number of production station) and space information (assembly line, work space and storage). In the work activity information module, for work activity analysis of As-Is modular production, select the type of the module unit. Depending on module usage such as education, residential or office, there are many different types of material, configuration of the unit, scale and so on, for the work activities in the factory production. Work activities classified as work character, divided into building, electric and facilities are extracted through field analysis, then activity sequence and dependency of the work is investigated. The work activities of the modular construction involved complexly at each work station and work done are carried out simultaneously in contrast to on-site construction. Therefore, considering this feature is very important.

3.2.2 Production Rearrangement Processing Module

In the production rearrangement processing phase, it mainly consists of organizing activity map through DSM modeling. By using the dependency and sequence information of the work activities that were analyzed by work type in the factory, the partitioning algorithm is applied. Through this process, work activities of the modular factory is rearranged as optimized work

information changes (in this study, work information means work sequence arrangement), and modularized activities which mutually exchanges the work information. Then, using this DSM model, I developed activity process map to utilize factory work. To make the activity process map of the modular factory, work activity is sorted by factory or document analysis. Then, modularized activity modules allocated in sub assembly line for precast production. Other sequential activities were allocated in main assembly line. Then synchronized work time per station that is about one hour through activity re-allocating.

3.2.3 Framework Result Analysis

The output represents the work activity management method and factory layout. Creating the activity map based on DSM model is used as basic data for the management of plant module mentioned above. Based on this, the layout of the factory and work flowchart was created. Work activity map show work flow focused on activity and factory manager can make a production plan. Through work flow chart, factory manager can easily predict the entire module production process and check the work activity process. Also, modularized activities are independent from main assembly but have strong internal dependencies among the activities. Therefore, the manager can check work quality for each module separately. Finally using an activity map of K modular factory, factory layout based on activity work flow can be suggested. Factory work space is reconfigured by excluding the physical changes of the factory such as line expansion or distortion in the existing

factory. Existing mainline can be separated as one mainline and sub assembly line to introduce a precast production system.

Activities that are conducted in the sub assembly line are consisted of combined module which are clustered in DSM model aimed to correlate object modularization and work standardization.

3.3 Summary

In this chapter, the DSM modeling process and framework for applying the modular factory is suggested. DSM modeling process consists of sorting the modular factory work activities and analyzing dependency between the activities and rearranging activities for smooth work flow. This process consists of three modules: Activity Analysis; DSM Modeling; and Line Applying module. And then, in order to apply the modularization production process to modular factory, a framework for applying modular factory that derived from DSM modeling based work information exchange presented in the DSM modeling process is suggested. Also, factory layout alteration needs to be done as well as rearranging work activity module allocation.

Chapter 4. Case Study (Factory Analysis)

In this chapter, this study introduced a case study to verify the developed DSM framework model. The case study was conducted with a real modular factory in Hwaseong-si, Gyeonggi-do and Bachelor Officer's Quarters (B.O.Q) Project. Also it demonstrated the significance of research and application.

Through this case study, whether the bottleneck effect caused production delay from complex activity relationship and if the mutual dependency affects the modular factory production system was studied. Then verified whether the effects from activity sequence rearrangement and clustering through DSM methodology can decrease complexity of the modular production system. Finally, management method and factory layout based on the DSM model was suggested.

4.1 As-Is Process Analysis of K Modular Factory

4.1.1 Target Modular Factory Outline

K modular factory, located in South Korea, is selected as the research factory has two modular lines and an I-shaped process layout design. 11 units per one modular line can be traced and there are total of 11 processes. One process work takes about 50 minutes and appropriate one day production capacity is 8 EA (Table 4-1).

Table 4-1 K Modular Factory Outline

Index	Contents
Location	Hwaseong-si, Gyeonggi-do, South Korea
Factory Area	4000 m2
Number of Station	11
Daily Production Capacity	15 EA
Production Type	Steel Frame Modular
Module Hoisting Method	Crane(2EA), Forklift

4.1.2 Bachelor Officer's Quarters (B.O.Q) Project Outline

The subject that chose to analyze and modularize the work process, the bachelor office's quarters (B.O.Q) project was selected. The B.O.Q project is an accommodation supply project for the national military officer. The project includes the entire scope between construction design to completion, and they selected modular construction method as they had to provide residential facilities quickly for the entire country; approximately thirty separate sites within six months. Hence, there are possibility of potential bottlenecks and delays that occur in the process of line production in the short-term unit mass production; it is essential to present a modularization study to smooth the production flow. In addition, for the strategic purpose of the military camp, is the modules are considered for removal in the future. Hence, modular construction method was selected as a military project that is reusable and portable in the future. To module process analysis, accommodation modules were selected as it can represent the other module's characteristic. Details of the B.O.Q project are as follows.

Table 4-2 Bachelor Officer's Quarters (B.O.Q) Project Outline

Index	Contents
Project Name	Bachelor Officer's Quarters Construction Project
Construction Site	Gapyeong Gyeonggi-do et al. 29 Site
Module Ordering Quantity	1,186 EA
Total Construction Duration	180 Days
Construction Scope	Module Fabrication and Site Assembly

4.1.3 Analysis of K Modular Factory Activities

After selecting the factory to analyze and project for process rearrangment, to sort the activities of modular factory and analyze the relationship of the activities, work checklist through labor and manager interview was created. Checklist consists of activities per station, activities name, activities contents, labor input, work importance and predecessors.

An example of checklist is as shown below (Figure 4-1).

•공종별 체크리스트 작성

1번 공정

	작업내용	내용 및 체크사항	중요도	투입 인원	선행작업
건축	1. 코너몰딩(4개소)	철골프레임 제작을 위해 비워두고 타설하였던 코너 부분의 몰딩을 진행		1	철골프레임
	2. 일체형벽체(2면)작업 - 내부코킹시공	런너>스터드>방화석고보드 순으로 작업	★	3	X
	3. 단변벽체 STUD설치 (창,복도)	런너>스터드		1	철골프레임
	4. 창틀보강(100*50)- 창틀 및 문틀설치	스터드 설치 후 작업 기 조립 후 스터드에 정착(철골프레임에는 플레이트 설치 후 볼트조임)		2	건축3(단변벽 STUD설치)
	5.G/W설치 - ①번방향	이 작업은 장변에 내부방화석고보드 설치 후에 진행되며 작업전에 콘센트 및 전기배선 구멍을 내주어야함 G/W을 고정하기위해 핀을 미리 방화보드에 설치		1	1-건축2
	6. 외부 CRC 보드① 테두리 코킹 포함	현장에서는 후속작업으로 밀림(본 공정과는 달리 1,2,3,4,번 방향의 비슷한 공정을 한번에 처리)		3	1-건축5
설비	1. 입상배관(P/S)	온수기 및 설비시설을 위한 배관		1	철골프레임, 1-건축2
	2. 온수기 설치	온수기가 필요한 유닛에만 설치		1	철골프레임
전기	1. 일체형벽체 배관 취부	장변의 스터드에 고정시키는 배선박스, 이를 위해 석고보드에 구멍을 내는 작업이 필요, 위치의 정확성 必	☆	1	1-건축2
	2. 단변부 A/C BOX 취부	단변의 스터드에 고정시키는 배선박스, 전기 1,2 후에 전선관을 천장과 결속시키는 작업수행 이 이후에 G/W 설치		1	1-건축3

Figure 4-1 Modular Factory Inspection Check List

Through the progress schedule and site analysis, drawings of total 65 work activity information relationships are shown in Table 4-3. Each activity is given an ID number as present process order and then classified into the work type. After, analyze the predecessor that can precede before next work activities.

Presented in Table 4-3, the activities listed as relation map for each station is shown in Figure 4-2. This activity map shows work sequence relationship of the entire fabrication work process of a one unit frame assembly to inspection and also visually shows work flow and work production delay intersection intuitively. Through this activity map, it can know immediately from station 1 to 4, activities are combined intricately.

Table 4-3 K Modular Factory Activity Relation Analysis

Group	ID	Activity Name	Predecessors
Building	1	Steel frame processing	
Building	2	Steel frame rust & fire preventative	1
Building	3	Steel frame assembly	2
Building	4	Floor concrete forming	3
Building	5	Install bathroom floor	4
Electric	6	Install integrated frame roof	3
Building	7	Corner floor concrete forming	4,5
Building	8	Install wall runner (long side)	3,9
Building	9	Install wall stud (long side)	3,8,17
Building	10	Install gypsum board (long side)	8,9
Building	11	Install wall stud (short side)	3,4,5,12,18,19
Building	12	Install window & door frame	3,11
Building	13	Set glass wall (left long side)	8,9,10,17
Building	14	Install cement board (left long side)	8,9,13
Facility	15	Install pipe duct	3,5,6,16
Facility	16	Install water heater	3,6,15
Electric	17	Set wall piping (long side)	9,10,14,21
Electric	18	Set A/C box (short side)	11,24
Building	19	Install gypsum board (short side)	11,18
Building	20	Set glass wall (right long side)	8,9,10,17
Building	21	Install cement board (right long side)	8,9,20
Facility	22	Install air & waste duct	3,4,6
Building	23	Set bathroom stud	3,4,5,6,10,11,26,27,29
Building	24	Set Glass wall (short side)	11,12
Building	25	Wrap water proof paper	13,20,24
Facility	26	Install bathroom wall	23
Facility	27	Install bathroom ceiling	23,26
Facility	28	Install air conditioner pipe	3,5,6,46
Electric	29	Set bathroom electric box	23,26,30,32
Electric	30	Connect bathroom electric wiring	6,29
Electric	31	Set taxi light box	11,24
Building	32	Install bathroom glass wall & gypsum board	23,29,30
Building	33	Install cement board (short side)	24,25
Building	34	Install external steel panel	3,24,31
Facility	35	Install bathroom door	23,32
Electric	36	Connect electrical line	29,30,31
Building	37	Install finishing steel panel	3,25
Building	38	Install air conditioner plant	37
…	…	…	…
Building	65	Inspection & packing	64

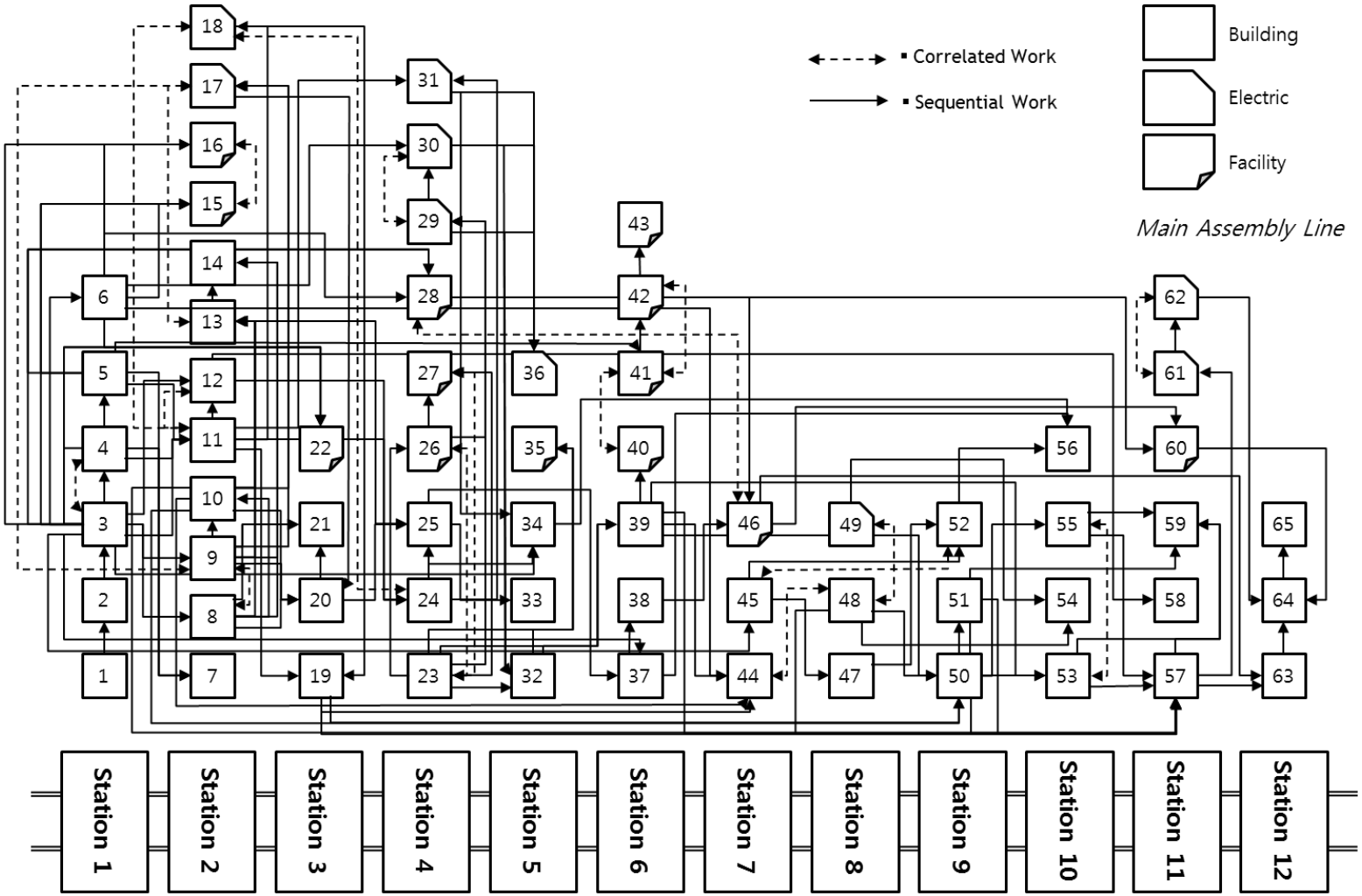


Figure 4-2. K Modular Factory As-Is Activity Map

Also, since too many activities are conducted on the main line, it causes many accidental problems such as the bottlenecks occurrence, delays in production lead time, difficulty of securing consistent quality and changes in the order process. Hence, in this study, improved solutions will be presented.

(1) DSM modeling using the analyzed activity

(2) Optimized list processed as information flow

(3) Correlated activities modularization

(4) Dividing into main and sub production line with 64 activities. (Based on DSM modeling)

(5) Establishing precast production system as pre assembly departed activity

4.2 DSM Modeling of Work Activity

Implementation of partitioned DSM for activity rearrangment and modularization, using the activity relation in Table 4-3, command is inputted as shown in Figure 4-3.

As shown in the Figure 4-3, many activities are correlated and distributed widely. Many exchanges of activity information means complexity of the process and scatter on the diagonal activities implies congested flow of the construction information. Also, above the diagonal activities incur repetitive work causing ineffective process working on the modular factory. Therefore, each column and row of the matrix moves toward each other to eliminate the repetitive work and approach the diagonal to secure continuity of the work through activity rearrangement.

In Figure 4-4, the activity sequences are rearranged using partitioning algorithm as shown. It represents construction process that has optimized information exchange sequence. Then, information interaction intervals are tied to the box which means that each section has a strong interdependent work.

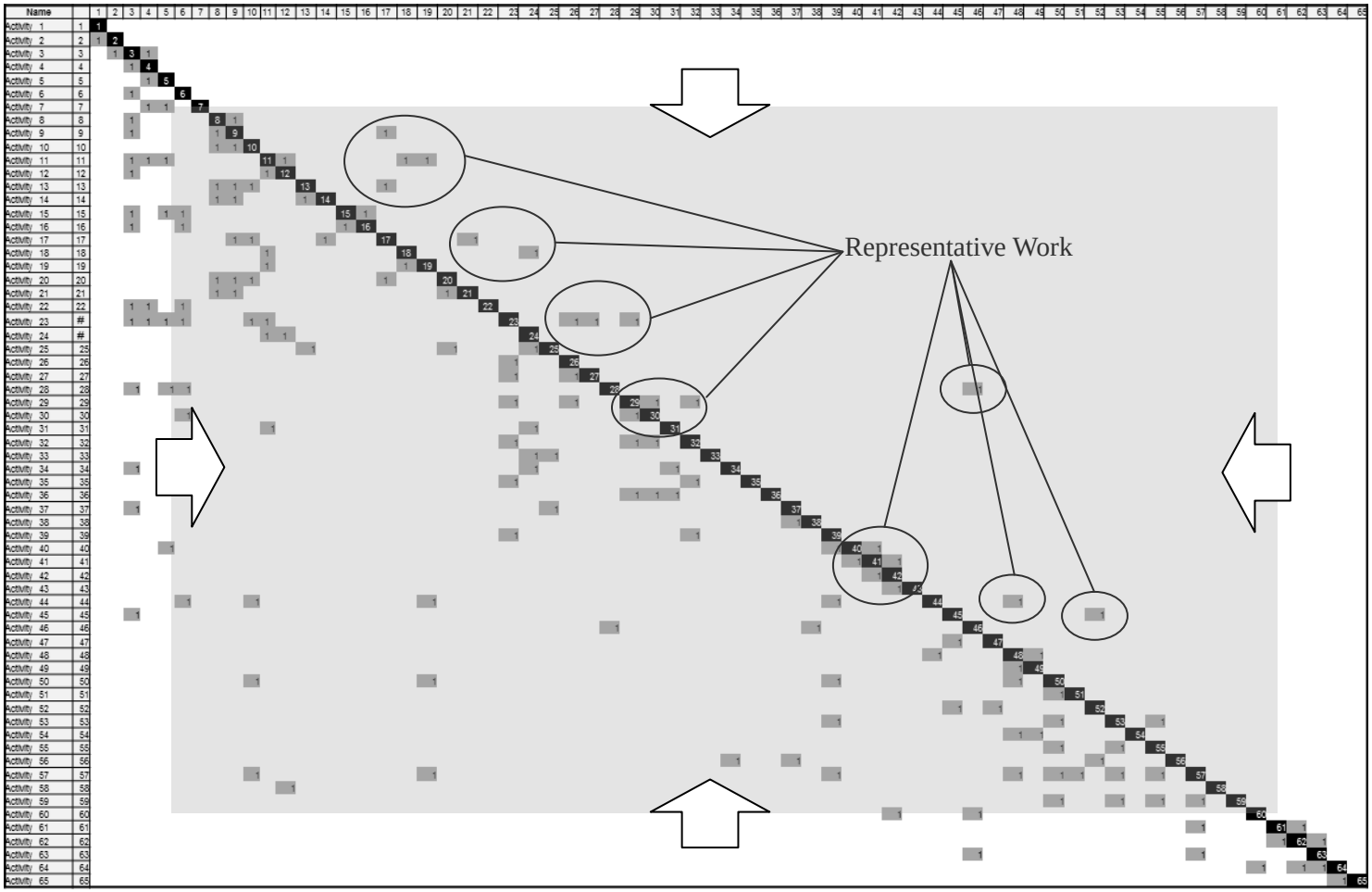


Figure 4-3. Implication of DSM Model

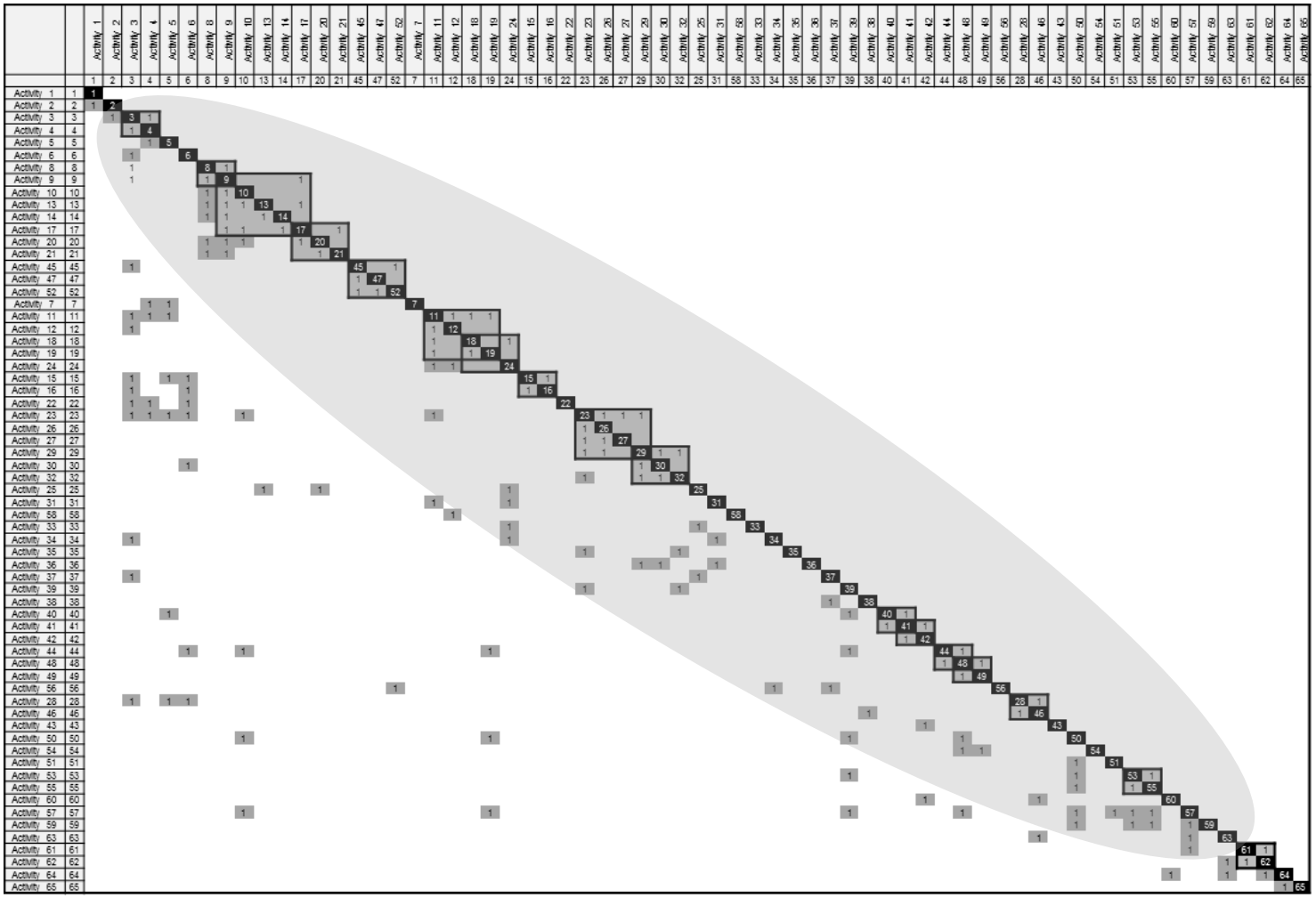


Figure 4-4. Implication of Partitioning Algorithm

Chapter 5. Case Study (DSM Model Application)

5.1 DSM Model Analysis

Partitioning algorithm proceed based on gathering mutually correlated activities and rearranging activity order to optimize information exchanging.

As a result of partitioning algorithm, column and row of matrix in Figure 5-1 are rearranged closely to the diagonal of the matrix to secure continuity of work and minimize the repetitive work activities on the above the diagonal to below. After utilizing partitioning algorithm, activities [3,4] [8,9] [9,10,13,14,17] [17,20,21] [45,47,52] [11,12,18,19] [18,19,24] [15,16] [23,26,27,29] [29,30,32] [40,41] [41,42] [44,48] [48,49] [28,46] [53,55] [61,62] are tied as the interdependent box. Activities in the tied box need special attention during fabrication due to mutual exchange of information. Thus, these activities have to be separate from the main assembly line and prefabricated in the subassembly line. Clustered activities do not only mean mutually correlated but also product oriented part such as frame, wall, roof and UBR (Figure 5-1).

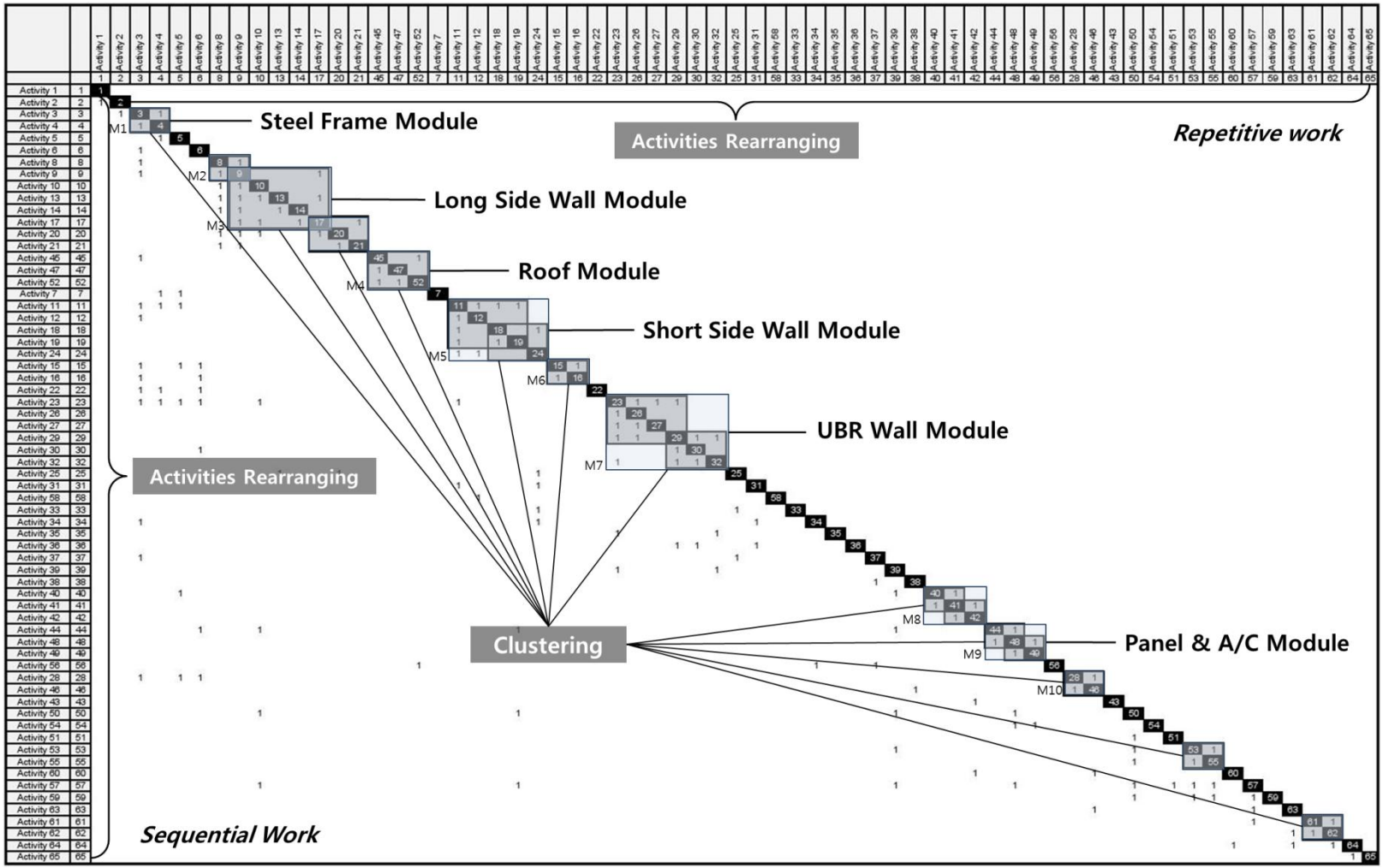


Figure 5-1. DSM Model Analysis of K Modular Factory

Work sequence is also changed to product oriented. For example, before applying the algorithm, wall construction process begins with setting a stud and runner to long and short side of the wall [9, 10, 11, 12, 13 activity], installing plumbing and electric equipment [16, 17, 18, 19 activity] then setting a glass wall and CRC board [14, 15, 20, 21, 22, 25 activity]. However, after applying the partitioning and clustering algorithm, the process begins with installing stud and runner, setting plumbing and electric equipment, then setting a glass wall and CRC board to the long side wall as seen in Figure 5-1 [8, 9, 10, 13, 14, 17, 20, 21 activity] and repeating the same procedure on the short side wall [11, 12, 18, 19, 25 activity]. This means that work process changed to object-centered and working relationship-centered. Clustered activities influenced each other with work quality as they mutually exchange construction information. Such activities should be managed as precast production system as tide activity module such as wall activity module, UBR activity module and roof activity module. Therefore, these clustered work modules have to done at the same station for efficient work and management as seen in Figure 5-2. Also, modularization fabrication process clusters the mutually related activities to the modular production, where it is possible to manage the mass production system through module work standardization and rework trigger activities management.

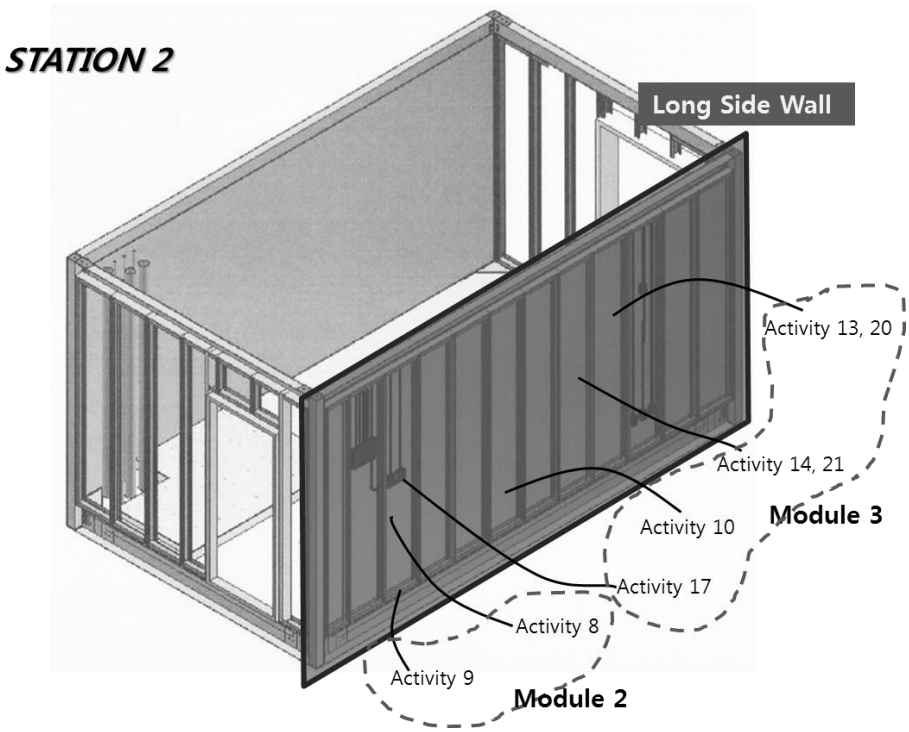


Figure 5-2. Product Relate Based Work Activities

5.2 Management Method of Modular Production Process

Using the rearranged activities through DSM method, work manager of the modular factory can manage work delay.

First, extract the number of give information to the other X activities and receive information from other activities for each activity (Table 4-4). If the activity information is given a high number, depending on the working quality of the predecessor, the following many activities are influenced. Hence, the factory manager would have to allocate skilled workers for the activity. If the activity information number is high, this activity can be used to determine the rework point or to check the quality of work.

Table 4-4 K Modular Factory Activity Information Relation Analysis

Activity order		Number of give information to X activities			Number of receive information from X activities		
Before	After	Forward	Backward	Total	Forward	Backward	Total
1	1	1	0	0	0	0	0
2	2	1	0	0	1	0	0
3	3	14	0	14	1	1	2
4	4	5	1	6	1	0	1
5	5	6	0	6	1	0	1
6	6	7	0	7	1	0	1
7	8	6	0	6	1	1	2
8	9	6	1	7	2	1	3
9	10	7	0	7	2	0	2
10	13	2	0	2	3	1	4
11	14	1	0	1	3	0	3
12	17	1	2	3	3	1	4
13	20	2	0	2	4	0	4
14	21	0	1	1	3	0	3
15	45	2	0	2	1	1	2
16	47	1	0	1	1	0	1
17	52	1	1	2	2	0	2
18	7	0	0	0	2	0	2
19	11	6	0	6	3	3	6
20	12	2	1	3	2	0	2
21	18	1	1	2	1	1	2
22	19	3	1	4	2	0	2
23	24	4	1	5	2	0	2
24	15	1	0	1	3	1	4
25	16	0	1	1	3	0	3
26	22	0	0	0	3	0	3
27	23	6	0	6	6	3	9
28	26	2	1	3	1	0	1
29	27	0	1	1	2	0	2
30	29	3	1	4	2	2	4
31	30	2	1	3	2	0	2
32	32	2	1	3	3	0	3
33	25	2	0	2	3	0	3
34	31	2	0	2	2	0	2
35	58	0	0	0	1	0	1
36	33	0	0	0	2	0	2
37	34	1	0	1	3	0	3
38	35	0	0	0	2	0	2
…							
65		0	0	0	1	0	1

5.2.1 Process Managing Using Work Activity Map

The optimized process derived from DSM modeling is applied to as-is process; and then an improved factory fabrication process (Figure 5-3) is developed. The total number of stations is the same as the existing process. The existing factory main assembly lines are divided into two processes as main-sub assembly line as a result. Then the number of main activity is decreased from 65 to 43. Also, the number of information exchange in the main assembly line is reduced dramatically (Figure 5-3). Furthermore, it will decrease the construction information length between each work phase – reducing the latency of the following process that helps continuous construction. This represents smooth flow of information, and will lower the possibility of accidental bottlenecks occurrence. Moreover, this optimized process will make the factory management easier.

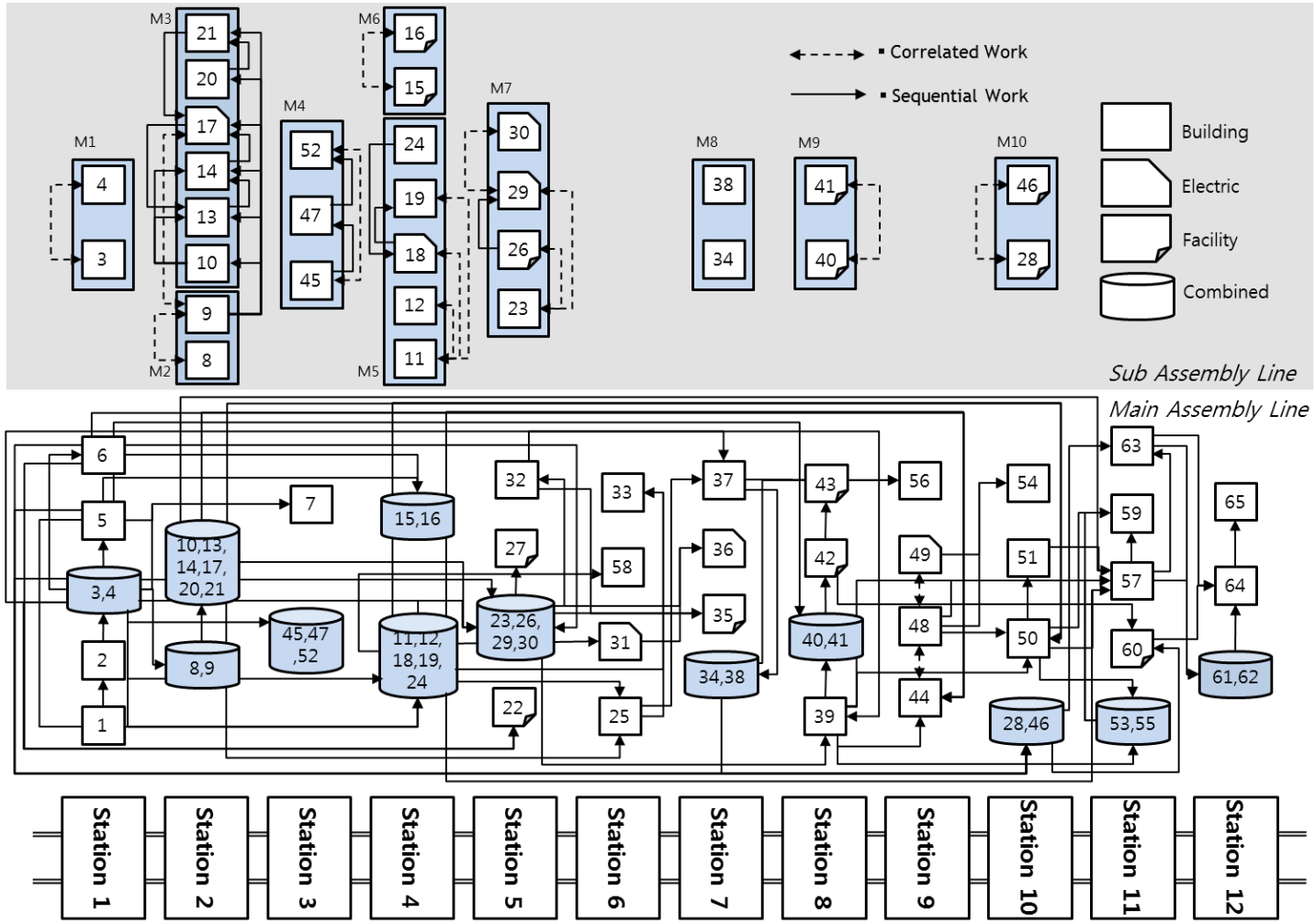


Figure 5-3. Work Activity Map Suggestion of K Modular Factory

5.2.2 Process Managing Using Work Flow Chart

Using the work activity map of K modular factory, a simple work flow chart for factory work management (Figure 5-4) was developed. Through this work flow chart, factory manager can easily predict the entire module production process and check the work activity process. Also, modularized activities are independent from the main assembly but it has strong internal dependencies among the activities where the manager can check the work quality for each individual module.

In the present K modular construction process, work inspection of the module quality occurs only once at the end of the work process. Therefore it is hard to treat and recover negligence of work. However, by setting the inspection interval for each module by the workflow chart, it can serve to improve the overall work quality of the module.

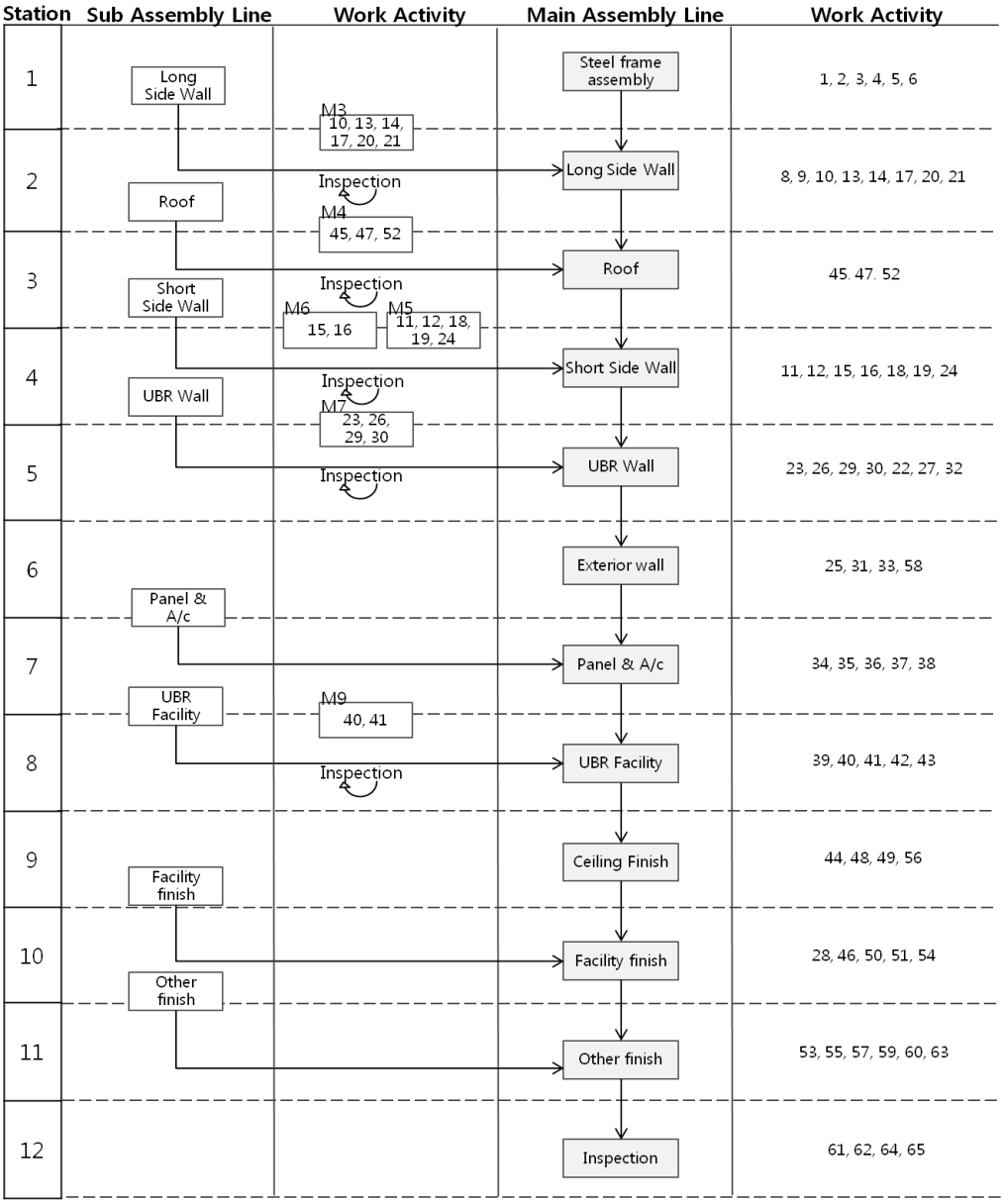


Figure 5-4. K Modular Factory Work Flow Chart

5.3 Factory Layout Suggestion

Using an activity map of K modular factory, factory layout was suggested (Figure 5-5). Factory work space was reconfigured, excluding physical change of the factory such as line expansion or distortion in the existing factory. The existing two mainline was separated as mainline and sub assembly line respectively to introduce precast production system.

Activities that are conducted in the subassembly line consists of combined module that was clustered in DSM model aimed to correlate object modularization and work standardization.

Existing process of the K modular factory is organized as time-series based activity allocation, similar to the typical construction process. Hence, main part of the process such as wall, UBR, and floor construction continue over two or three other stations. As a result, the complexity of the process increased as various types of work began to overlap. Also, As-Is activity allocation does not consider dependency of the activities that causes repetitive work and eventually induces work delay from bottleneck occurrence.

Therefore, the factory layout base on clustered work module was suggested. High dependent work module such as wall, floor, and ceiling was modularized as an object based and was conducted in the subassembly line. To prepare the subassembly and supply the material for each station, feeder space is divided for work feature.

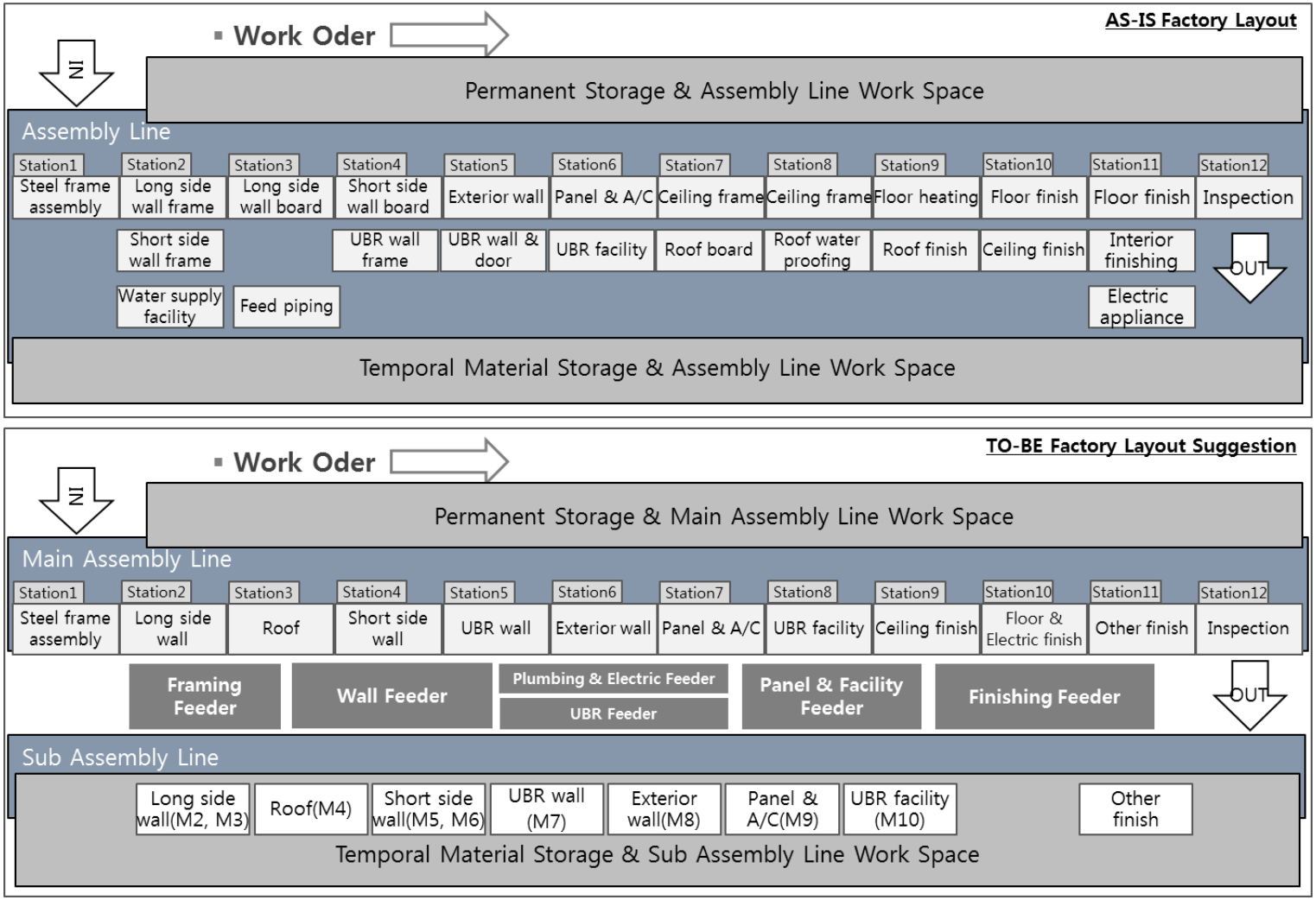


Figure 5-5. Production Layout Suggestion of K Modular Factory

5.4 Summary

In this chapter, the case study was carried out to verify the developed DSM framework model that was suggested in Chapter 3. Case study was conducted with a real modular factory and Bachelor Officer's Quarters (B.O.Q) Project. For this, work activity information relationship of the K modular factory and relation map was analyzed. Using the analyzed activity relationship, DSM modeling was conducted. As the result, activity orders were rearranged and the numbers of information exchange of the main assembly line were reduced dramatically. Then, using the DSM model of K modular factory, factory management support tools was developed, which is the work activity map and work flow chart for the factory manager. And finally, the production layout of the K modular factory based on activity work flow was suggested.

Chapter 6. Conclusion

To solve this production problem, modular factory production management method was suggested to improve the modular factory production flow. The suggested method can decrease the complexity of the overall modular production process by modularization of the work activities and rearrange of the work activity for the sequential work flow. For activity rearrangement and clustering based on activity information, Dependency Matrix Methodology was used and to apply modular production, the applying process and framework was suggested. Also, to verify the developed DSM framework model, case study was conducted with a real modular factory. Using the DSM model, modular factory management tools such as work activity map, work flow chart and factory layout was suggested. This result can reduce the possibility of the rework and there is a minimum bottleneck occurrence in the fabrication stage of the modular factory. Hence, this will enable the smooth production flow and a more efficient management.

6.1 Research Result

(1) Analysis Modular Factory Production System and Problem

To solve the production delay problem in the modular factory, site inspection was carried out and modular production activity map was created. Activity map can visually shows the work flow & work production delay intersection

intuitively. Also the cause of work delay, which was the bottleneck effect from mutually related activities and system complexity was established.

(2) Proposed Modular Factory Activity Rearranging Model

In order to decrease system complexity of the factory production process rearranging work activity order and clustering was suggested. For this, a conceptual model was presented to take advantage by applying to a DSM technique to an actual module factory. For work information flow based, process consisted of activity analysis module, DSM modeling module and process application module. Through the DSM modeling process for modular factory, factory manager can rearrange activity order by optimizing information flow and cluster correlated activities that require special attention during fabrication due to mutual information exchange that causes rework and bottleneck effect.

(3) Proposed Framework for Applying DSM Model to Factory

In order to apply the modularization production process to the modular factory, derived from DSM modeling based on work information exchange, factory layout alteration has to be done as well as rearranging work activity module allocation. Therefore the framework for applying DSM model to factory was suggested. The framework consists of input information, production rearrangement processing and output. Using this framework, factory manager can acquire work managing tools: work process map; work flow chart; and work relation based factory layout. Using these tools, the

manager can easily predict the entire module production process and check the work activity process. Especially work relation based factory layout can improve production delay problem promptly, cheaply, and efficiently without factory and line extension.

6.2 Contribution

(1) Provide Management Tools of Modular Factory

Modular system is fundamentally a construction industry but there are many manufacturing characteristics and obstacles in the factory process. Hence factory management tools considering characteristics of construction and manufacture industry was suggested. Based on work related modularization production system, work managing tools such as work process map, work flow chart, and work relation based factory layout were suggested. These types of tools can help predict work operation and quickly find solution of the production delay for the manager.

(2) Proposed Large Extensibility DSM Method

With proposed modular factory DSM model, this paper can be applied to a modular factory management tool in new types of plants or various module unit types. Also, as these suggested management methods do not consider remodeling or expansion of the factory facilities, it can be applied to many existing factories. Furthermore, this optimized plan can have a ripple effect in

the future studies: factory design planning, material supply, worker management, transportation, and etc.

6.3 Limitation and Future Study

The limitation of this study is that the study is not fully validated with actual quantitative work resource as the Korean modular industry market is at the introduction stage. Therefore, modular factory work data is not accumulated. Also, the factory and module case study is limited as it is already an existing factory and one type unit. Therefore in the future study, it is necessary input the theory of DSM-based management system in practice for other cases or new modular factories in order to draw a more meaningful result and validate the data using the quantitative activity work time.

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국 문 초 록

모듈러 공법은 바닥, 벽, 천장 등 골조를 비롯한 전기, 설비 시설에 이르기까지 건물의 80% 이상을 공장에서 시공하는 프리패브 기법을 말한다. 모듈러 공법은 공장생산시스템 특성으로 인한 공기단축, 재료 재사용의 용이함, 설계비경감, 원가절감, 건설폐기물 및 이산화탄소배출 저감 등 많은 장점이 있다. 최근 전 세계적으로 이러한 모듈러 공법의 특성을 활용하여 군 막사, 학교, 사무실, 주거용 등 다양한 형태의 건물시공에 적용되고 있다. 모듈러 공법의 경우 기초 작업 및 현장조립 작업 분을 제외한 모듈 유닛 시공과정의 대부분이 공장 안에서 수행된다는 점에서 현장시공 기반의 공법과 큰 차별성이 존재한다. 모듈제작에 있어 외부환경에 영향을 받지 않으므로, 날씨에 의한 공기의 지연, 작업자의 안전 위험, 작업 난이도 상승 등 외부요인으로 인한 리스크를 획기적으로 줄여준다 이와 같이 모듈러 공법의 가장 큰 장점인 공장제작의 효율성을 극대화하기 위해서는 모듈러 유닛의 원활한 생산을 위한 체계적인 공장제작 프로세스의 구축이 필수적이다. 하지만 건물의 골조부터 마감까지에 이르는 작업을 하루 이틀 만에 수행하는 모듈러 건축의 특성상, 많은 작업 수에 의한 생산라인에의 병목현상의 발생, 재작업 발생의 위험성 등 모듈러 유닛생산의 생산성을 저해하는 요소들이 공장생산 시스템 상에 존재한다.

따라서 이들 작업액티비티간의 생산흐름을 원활히 하기 위한 작업배치가 필수적이며, 이를 생산계획 단계에서 고려한 최적공정 도출 및 관리는 모듈러의 원활한 대량생산을 위해 필요하다. 본 연구에서는 모듈러 유닛의 공장제작 프로세스를 작업액티비티 단계에서 최적화 하기위한 방법론을 제시하며, 이를 위해 DSM(Dependency Structure Matrix)방법론을 사용하여 작업 정보기반의 최적프로세스를 제시하고 이를 공장의 공간정보에 적용하기 위한 프레임워크를 제시하며, 사례적용을 통해 그 효용성을 검증한다. 결과적으로 DSM모델링을 통한 작업순서 재배치 후, 작업 액티비티간의 정보교환횟수를 50% 가량 감소시켜 생산지연으로 인한 병목현상 발생 가능성을 줄였으며 상호 연관관계가 높아 재작업이 우려되는 액티비티들을 모듈화 하여 집중관리하기 위한 생산방법과 이를 위한 공장 레이아웃을 제시하여 본 연구의 활용가능성을 높였다.

주요어: 모듈러 시스템, 프리패브 건축, DSM (Dependency Structure Matrix), 모듈화

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