Master of Science in Engineering

Production Scheduling for Multi Project Modular Construction based on Genetic Algorithm

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Abstract

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The modular construction has several advantages such as high quality of product, safe work condition and short construction duration. The production scheduling of modular construction should consider time frame of factory production, transport and erection process with limited resources (e.g., modular units, transporter and workers). The production scheduling of multi modular construction project manages the modular construction's characteristics and diversity of projects, as a type of modular unit, modular unit quantities, and date for delivery. However, current modular production scheduling techniques are weak in dealing with resource interactions and each project requirement in multi modular construction project environments.

Inefficient allocation of resources during multi modular construction project may cause delays and cost overruns to construction operation. In this circumstance, this research suggests a production scheduling model for schedule optimization of multi project of modular construction, using genetic algorithm as one of the powerful method for schedule optimization with multiple constrained resources. Comparing to the result of the existed schedule of case study, setting optimized scheduling for multi project decreases the total factory production schedule. By using proposed optimization tool, efficient allocation of resource and saving project time is expected.

Keywords: Modular Construction, Modular Unit, Multi Project, Genetic Algorithm

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Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

This chapter presents the research background, problem statement, objective and scope in modular construction. Also, at the end of this chapter, main research process is described with research process figure.

1.1 Research Background

The modular construction is composed of modular unit production in off-site factory and erecting it on-site (Mohsen et al. 2008). A production works in a factory should be planned to take into account the schedule of on-site construction works because those two works operate at the same time. To do this, predicting the duration of modular construction process from modular unit production in factory to transportation and on-site erection is required (Alvanchi et al. 2012). In addition, it is important that the production plan of the modular factory because the modular factory supplies modular unit at multiple projects not only for one project. Modular unit quantity, required type and due date are different depending on each project. Therefore, scheduling of the modular factory is required to reflect the individual production process of each project (Noh 2005). If multi project scheduling is not well planned, saving construction duration which is strongest advantage of modular construction will not happen at the end of the construction project.

This situation could decline the project profits.

On the other hand, current scheduling method of the modular factory is same as a way that is used in the general construction industry. Compared with general construction projects, modular construction is characterized by cyclic activities that require complicated analysis (Mansooreh Moghadam, 2012). However, the traditional way does not well reflect of space allocation and repetitive tasks which are essential for the modular construction scheduling (Harris 2006; Hosein Taghaddos et al. 2010). As a result, the current scheduling is inefficient for the resource allocation of modular construction. For example, on-site work was delayed by incorrect modular unit order of installation. Owing to the lack of space for modular unit storage, factory production line was halted (Kang 2007).

Researchers have conducted a study to develop a scheduling of modular construction efficiently. However, research of modular construction scheduling mainly focuses on the scheduling optimization on a certain site (Hammad et al. 2008; Mohsen et al. 2008). As considering the growing demands for modular construction buildings, modular factory production and ships modular units on multiple projects. In this circumstance, it is difficult to implement scheduling optimization method in practice. Therefore, multi project scheduling of modular construction have to reflect characteristics of the individual projects as the overall process of factory production, shipping and erection of modular units.

1.2 Research Objective

From many research, traditional modular production scheduling techniques are weak in dealing with resource interactions in multi project resource-constrained scheduling environments. Existing scheduling tools are designed to support mainly typical construction, without considering modular building's specific needs. (Mansooreh et al. 2012)

Overlooked trailer size and installation sequence were delaying onsite construction. Because of lack of storage space, factory producing line was stopped (Kang 2008). If multi project scheduling is not well planned, this could be made decline the profits of the project.

The objective of this research is to develop optimization model for modular unit factory. First, this paper is to define variables of required resources for multi project scheduling of modular construction from literature reviews and expert interviews. The results can be utilized as a basis for optimized schedule of multi project of modular construction considering factory, shipping and erection process. Through this research, we can understand critical activities of modular construction production scheduling and constrained resources. As final result, this paper develops production scheduling model that can be used to provide optimum schedule for factory manager on multi project environment of modular construction.

1.3 Research Methodology and Scope

This research present a model that possibly plans the modular factory production scheduling related with factory, transportation and on-site installation. For the research scope, exclude on site construction scheduling, (Ex, excavation, foundation work) of modular construction process. Also suppose the modular units are using same factory production line and same kind of type.

In case of Korea, Ministry of national defense has been ordered military facilities, barracks and bachelor officers' quarters as multi project modular construction. In this paper, like those orders, confine research scope for multi project of the same type of project.

To solve the problem and to accomplish the objectives written above, this research should have the process. The research process is described at this lower page and illustrated as follow.

1) Analyzing existing problems of modular construction factory scheduling when they support multi project and selecting research methodology to solve the problem
2) Research about Genetic Algorithm as an optimization methodology and suggest apply method for this research
3) Finding out variables which reflect modular construction factory scheduling during modular unit production, transportation and on-site construction process when support multi project

4) Developing modular construction factory production scheduling optimization model with genetic algorithm based on the selected variables
5) Using optimization model, the effectiveness of the scheduling model is verified through case study and analyzing model output

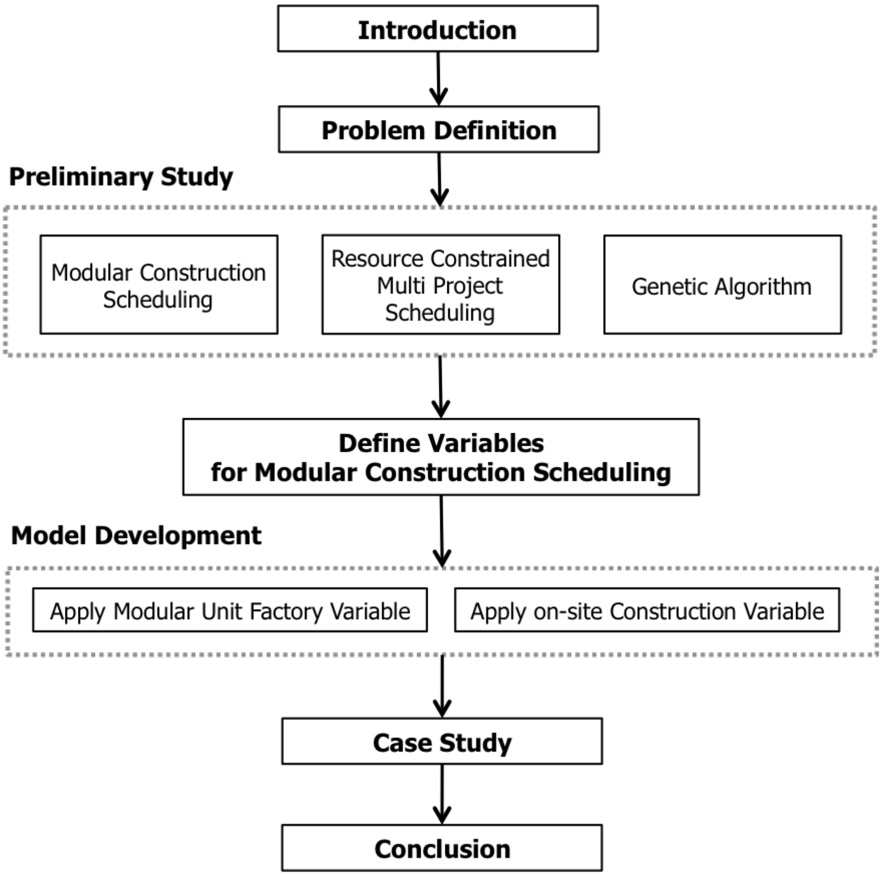

Figure 1-1. Research Process

Chapter 2. Literature Review

This chapter carries out the preliminary research for selecting methodology of research. At first, advantages of the modular construction and process of construction are introduced. Then literature review of modular construction scheduling and resource constrained scheduling is conducted. Also, limitations of previous research are discussed. Next, this study determines which optimal methods are adequate for the research. Lastly, the basic principle of genetic algorithm is described and applying process is presented.

2.1 Characteristics on Modular Construction

Modular construction is part of industrialization construction, which is construction method to install and assemble modular units (Lawson 2008). Modular unit is a structure which makes one solid space composed of three dimensions. Each modular unit is produced in modular construction factory. It has component of floor, wall, mechanical, electrical and finishing. Modular unit is designed at architecture firm, produced at factory and installed on-site (Kim et al. 2013).

Different from general construction, modular construction can minimize construction duration through factory production and on-site installation (Kim et al. 2014). Also, modular construction can get continuous quality of modular unit, mass production is possible through repetitive works (Kim and Lee 2014). When doing on-site construction, using connection place and bolt for binding point of modular units can make it reusable to dissembling. Based on those advantages, modular construction is used at military, education facilities and housing which has repetitive plan. Fig 2-1 describes modular construction process.

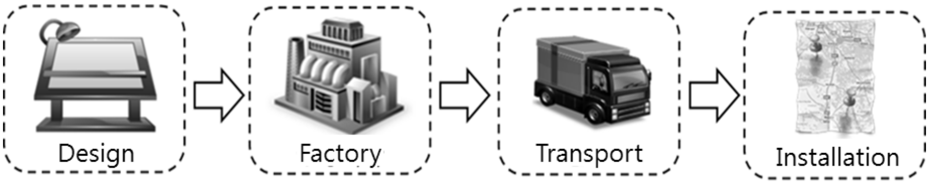

Figure 2-1. Modular Construction Process

2.2 Multi Project Factory Production Scheduling

According to the Mansooreh (2012), the scheduling method of modular construction is same as traditional construction industry. Scheduling of traditional construction is used to predict total duration based on activities' duration time and precedence relation (Kim 2014). However, constrained resource is different when performing multi project of modular construction and typical construction projects to apply the scheduling method in the same way. For the typical construction project, resource is managed by each site without sharing. However, in the case of modular construction, modular units which are produced in one factory support multi project. Thus, modular projects that are carried out simultaneously share the resources of the modular factory (e.g, modular unit productivity, workers, storage yard).

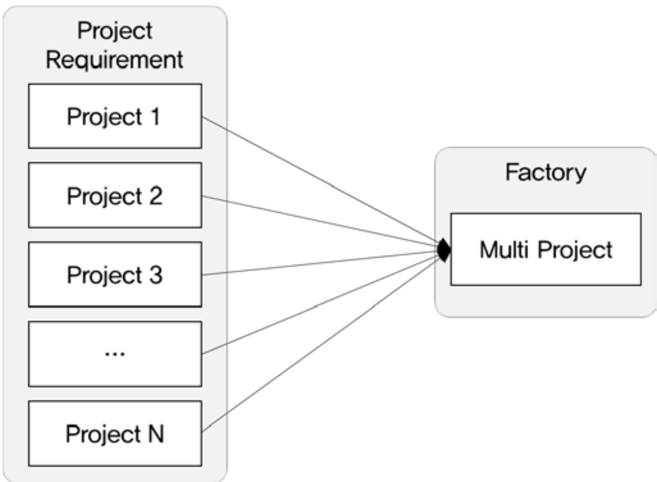

Figure 2-2. Multi Project of Modular Construction Concept

Fig. 2-2 is a diagram of multi project on a modular construction. First, modular unit production factory gathers the information of the individual projects. After that, establishing a comprehensive scheduling based on that information and provide to each project. Therefore, when scheduling a factory production process of a modular construction, it needs to consider the requirements of each project in addition to the limited resources.

When scheduling modular construction, not only the allocation of resource, but also the requirements of each project should be considered. Modular units are to be shipped on the date determined in accordance with the client request and on-site installation progress (H. Taghaddos et al. 2009). In addition, each modular unit's on-site installation sequence is fixed. Next modular unit cannot proceed with the installation, before prior modular unit installation is finished.

However, previous research about scheduling on modular construction mainly focused on the scheduling optimization on a particular site (Hammad et al. 2008; Mohsen et al. 2008). Therefore, research about multi project scheduling of modular construction is relatively insufficient.

In addition, the most research of modular construction scheduling is focused on optimizing factory production of modular unit (Jeong et al. 2006; Nasereddin et al. 2007; Yu et al. 2007; Hammad et al. 2008). A simulation model was proposed to improve the efficiency of on-site modular construction using a discrete event simulation (Mohsen et al. 2008). However, there is a limitation that previous studies did not handle the overall process, factory producing, shipping and installation of on-site.

Traditional modular construction scheduling assumes unlimited resources (Odeh 1992; Wang 2006; Kim 2007) and is inefficient to reflect repetitive activities (Harris 2006; Kim 2007). Therefore, the existing methods are not effective to reflect the constrained resources required by the modular construction. In addition, it is difficult to optimize the resources and the due date (Mohamed et al. 2007). The re-schedule due to the scarcity of resources or delay is difficult (Hosein 2014), so efficient way to schedule modular construction of multi project is required.

2.3 Previous Studies for Multi Project Scheduling

According to Payne (1995), 90% of business projects are in the context of multiple projects. Projects are planned individually and share limited resources. Modular construction scheduling of multi project should also be based on the constrained resources (Resource Constrained Multi Project Scheduling Problem; RCMPSP)

RCMPSP has been studied by a variety of methods. Methodologies which have been researched are exact method, heuristic method and meta-heuristic method.

The numerical approach is classified into linear programming (Kelly and Walker 1595), Integer programming (Meyer and Shaffer 1963) and dynamic programming (Robinson 1975). Those are local search technique to find optima output. However, it is difficult to have derived the optimal solution to handle the scheduling problem of large-scale (Deckero et al. 1991; Oguz and Bala 1994). In addition, construction managers do not bother to learn the mathematical knowledge in order to use this method (Vincent 2009).

A heuristic method determines principle of scheduling through certain criteria. This method has less computational element, so it is simple to handle. But it provides near-optimal solution and does not present a solution in alternative ways (Kumanan et al. 2006; Goncalves et al. 2008).

Meta-heuristic method which has been popular recently has a genetic algorithm as a representative method. The Genetic algorithm is widely used in practice related to the scheduling problem because it is easy to implement and highly reliable (Seren Tasan 2008). In particular, genetic algorithm in RCMPSP has been recognized for its efficiency (M. Gen et al. 2008).

Optimizing scheduling of multi project has been studied in factory production, shipping and construction industry. Meanwhile, modular construction needs a different approach from previous research because factory production and on-site construction are mixed in modular construction.

Modular unit factory production scheduling has many influence factors through modular production, transportation and installation process. Therefore, genetic algorithm could be effectively using for optimizing multiple variables on this paper.

Table 2-1 Methodology for Optimization

Methodology	Researcher	Contents
Mathematical approaches	Monhanthy and Siddiq 1989; Vercellis 1994	- Use to find the optimal solution in the local search area - Applicable to small-size problems - Few construction manager are trained to obtain the required mathematical knowledge - None of these procedures can be used for solving large-sized realistic projects
Heuristic techniques	Kumanan et al. 2006; Goncalves et al. 2008	- Rule is set based on experts opinion - Easy to apply and involve less computations - Do not provide a pool of the possible solutions according to different scenarios - only offer near-optimal solutions
Meta Heuristic techniques	Seren Tasan 2008; M. Gen et al. 2008	- Problem-independent techniques to find optimal solution - For scheduling problem, it is relatively easy to apply and highly reliable

2.4 Genetic Algorithm

A genetic algorithm is search algorithm to apply the principles of evolutionary to solve the optimization problem. This method applies nature world's evolutionary process that the most appropriate objects are only survived to engineering algorithm (J. Holland 1992). Since Genetic algorithm introduced by John Holland in 1975, it has been actively applied to transportation problem, traveling salesman problem, optimization combination problem, scheduling issues.

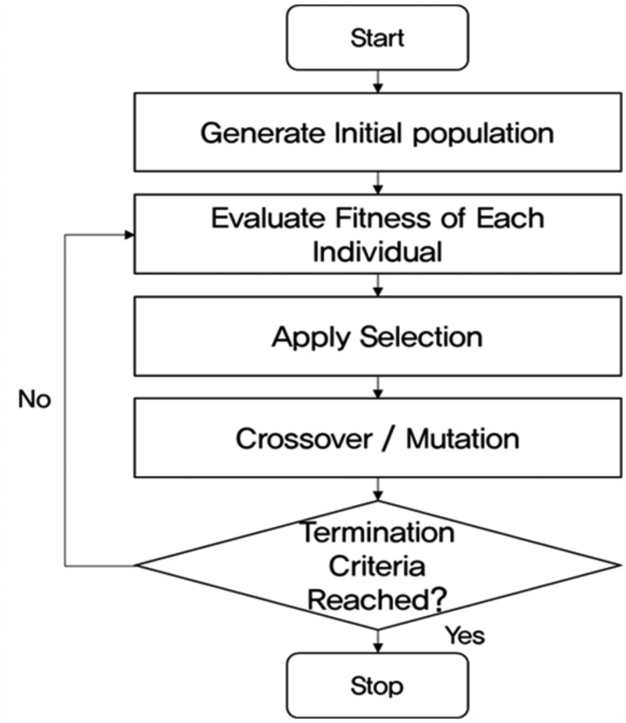

Fig. 2-3. Genetic Algorithm Flow Chart (Gilberto C. 2013)

Fig.2-3 is problem solve process of genetic algorithm. First, considering applicability of function, set genetic algorithm's form to effectively solve the problem. Second, set the parameter values (crossover value, population size, mutation value, stop option) which give great influence to output quality and time. Third, generate initial population depend random probability. Object which follow those steps has to select by require function and constrained (Kim 2004). Finally, selection, crossover and mutation function which are standard function of genetic algorithm will start. Crossover operator create two new generation to change some of their part depend on set crossover value. Mutation changes some part as totally new one, so it prevents to converge at some point. Each combination of chromosome is to replace each other genetic information according to the probability value, and creates a new object to derive an optimum value by the stop condition.

2.5 Summary

As a part of preliminary research, the modular construction method is introduced at 2.1. There are distinguishing characteristics compared with general construction. In section 2.2, literature review on modular construction scheduling and describe the concept of multi project on modular construction. Literature review on resource constrained multi project scheduling problem is analyzed by optimization method. Through this review, this paper chooses the genetic algorithm for optimization tool, because the research has lots of variables and constrained set to optimize. In section 2.4, the basic principle of genetic algorithm and process are described.

Chapter 3. Production Scheduling Optimization Model

This chapter defined influence factors for multi project modular construction. Through influence factors, develop the model for optimization modular unit factory production scheduling.

3.1 Variables for Multi Project Modular Construction

In this study, for the construction of the factory production scheduling optimization model that utilizes a genetic algorithm, analysis of the factors that influence into the status of multi project in the production scheduling of the modular unit factory has to be preceded. It has been derived through the previous studies and expert advisory that the influencing factors of multi project modular construction. Expert discussion and interview was conducted with six practical experts at two companies of modular construction factory in November 2014 and February 2015. Contents to organize this are as Table 3-1.

Table 3-1 Impact Factors of Multi Project Modular Construction

Variable		Relationship
Factory	Productivity of factory	- Productivity is different depending on modular unit type and number of workers - Scheduling has to reflect each productivity
	A sequence of producing modular unit	- Productivity is different depending on modular unit type and number of workers
	Storage yard	- Size of storage yard affects to scheduling of shipping
Transport	Number of Trailer	- Number of trailers for modular unit transport per day
	Transit Time (Limited speed, Distance)	- Calculate with distance from factory to site and limited speed - When performing multi project of modular construction, distance to the site will be different with each project
Construction	Duration	- Construction must be done by due date of owner's request
	Erection Sequence of on-site construction	- Factory producing sequence is affected by the installation sequence of on-site construction
	Modular unit type	- Depending on the modular unit type, required installation time is different
	Number of workers	- Calculating constructability of on-site installation based on workers
	Modular unit quantity	- Depending on the project size, required quantity of modular units are different

This study analyzed the factors affecting modular construction scheduling of multi project for genetic algorithm methodology. Impact factors of modular construction scheduling are defined as follows, according to modular building construction process through analysis of previous studies and expert advice.

3.2.1 Modular Factory

In case of multi project, the factory production sequence is closely related to the factory shipping schedule that which modular unit will be transported to which site. The factor production sequence is not always exactly same as shipping schedule. It needs to consider the productivity of modular unit in the factory, the size of storage yard of modular units, and actual construction site assembling sequence (Park 2007; Abu Hammad et al. 2008).

Even if all of modular units are produced in the same factory production line, the productivity of each type is calculated differently depending on the type and size of modular units. For example, if modular unit size is larger, more workers are required or more time is spent. Also, if modular unit size is changed from 3x6m to 3x9m, factory spends sometimes on preparation for changing of modular unit size. Once producing modular units is completed, these modular units are moved to the storage yard in the factory. The storage yard is an open space for modular units, which is kept it before shipping. Number of modular units which are contained by storage yard is depending on the size of the storage yard. The modular units are staking in a storage yard in accordance with size of storage yard and on-site construction sequence. If modular units need cure the concreted surface, keep it in the storage yard. If not or the storage yard is full, modular units could ship to the site without staking in a storage yard.

3.2.2 Shipping of modular units

The modular unit, which is ready to transport, is loaded on trailer depending on their size and weight (Kim et al. 2014). The maximum number of modular units which can be transported in a day are set in consideration of the transit time from factory to site and maximum usable number of trailers per day (Park 2007; Mansooreh et al. 2012). Loading the modular unit is going to be in a state of ensuring the safety of the modular unit, and the modular unit is packaged not to be affected by rainfall. A trailer which loads modular unit should be transported in compliance with the limited speed for their safety. Arrived modular units are inspected of material condition and dropped off on the site or erected directly from the trailer.

3.2.3 On-site construction

The on-site installation of modular unit is initiated from the steps that you can assemble the modular units after the foundation work is done on site. The number of required modular units of project is different because each project size is different. Each project plan is different, so installation sequence is different from the project (M. Mohsen et al. 2008). Each site establishes a construction schedule based on the number of modular unit installation per day in consideration of the ability of workers, equipment (e.g., crane) and modular unit size (Park 2007). For on-site installation, after install the first modular unit, next modular unit installation proceeds including welding between units. Depending on the project, first floor needs joint construction between the base and the modular units.

3.2 Production scheduling model Development

A process of multi project modular unit factory of production scheduling model proposed in this study is as Fig 3-3. First, based on the derived influencing factors on multi project modular unit factory, input necessary information for the factory production scheduling model. Second, by using a genetic algorithm, get the optimized production scheduling and transportation planning which satisfies factory constraints. Finally, based on the production plan and the order of installation in on-site, derive the production sequence of a modular unit at factory.

The purpose of the model proposed in this study is to optimize the factory production scheduling, while satisfying the constraints of a particular resource, factory production, transportation and on-site construction. The value to be minimized in the model is piled up modular unit quantity, which has to be reduced as much as possible. After production of modular unit, make it simultaneously transported and able to install on-site. It will reduce the total number of stocked modular unit per day and the objective function is as follow equation (1).

$$\mathrm{OC} = \mathrm{Min} \sum S_i \tag{1}$$

Where, OC: Optimal Conbination

S_i: Storage Modular unit quantity per day

Modular unit type in this study is represented by the chromosome (see Fig.3-1, 3-2), the numbers entered in each of the genes constituting the chromosomes indicates production quantity of modular units per day.

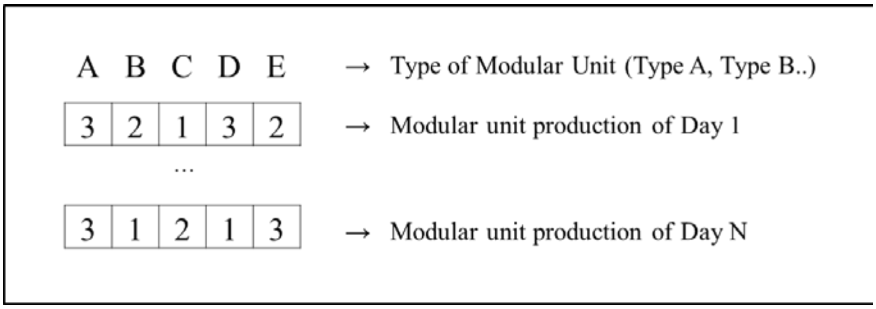

Figure 3-1 Production Unit Quantity Gene Combination

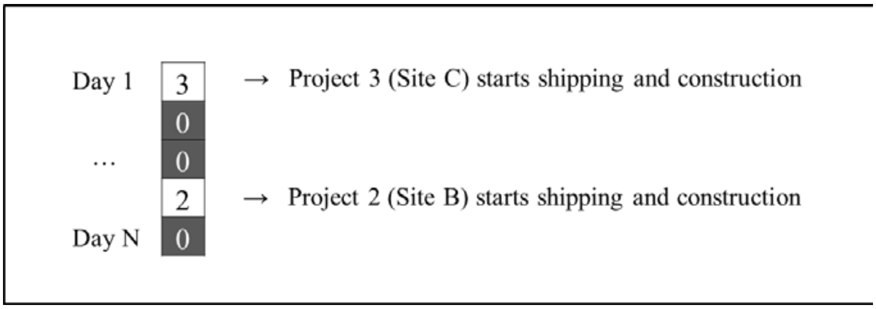

Figure 3-2 Shipping Date for Each Project Gene Combination

A combination of chromosome is increased according to the number of the required modular unit type changes JIG, the number of factory production line and the total construction period. JIG is an auxiliary equipment to fix modular unit when factory produce to make product same quality. It takes a certain amount of time to change another JIG. The combination of chromosomes, on the basis of the production volume of the modular unit per type, is object to derive production order of the modular unit factory. For example, if the numbers of individual genes are 3,1,0,0,3, A type and E type is produced quantity of three and B type is produced one. Because A, B type and E type have different modular unit size, it must be added JIG change time when producing them. Also, depending on each modular unit type, since the number of required production time or workers may vary, it is necessary to calculate the production time of the overall factory line by applying this. Daily production time was set to 8 hours. Total modular units produced at the factory are the same as the number of required units for all projects that have been determined at the time to create a factory process table.

A chromosome of Fig. 3-1, the production volume is determined to meet the requirements of each project at the time of execution of multi project. Modular unit produced at the factory, that needs to be transported in accordance with the schedule required in the field, will be set to be shipped according to the time when foundation work is completed for each site. Therefore, the modular units, which are produced prior to the transportable day, have to wait for transportation by loading the storage yard in the factory. Equation (2) shows the number of modular units that are stacked field, is a value obtained by subtracting the number of installation to the sum of the previously number of modular units that exist in the field and production modular unit on the day.

$$S_i = S_{i-1} + P_i - E_i \tag{2}$$

Where, P_i : Producing Modular unit per day

E_i : Installed Modular unit quantity per day

The modular unit to be transported to the installation site will be shipped from the storage yard in the order defined along the building plan of each project. All the modular units that are assembled in the on-site will have the information about construction time at the required site in accordance with the modular unit type. For example, construction time by modular unit type refers to the time information that how long those it take to install the case of the 3x9m modular unit or the 3x6m modular unit when the team made up of eight people works. All assumption from this model is as follows.

1. Worker's Productivity for modular unit producing is same
2. Working hours per day set 8 hour for factory and on-site
3. On-site Installation date is fixed with Early start/Late start
4. Once on-site installation starts, the site will finish the installation work with their maximum installation units per day
5. Producing Modular unit and Installation is assumed to be normal. Unexpected delay or rework is not considered
6. 3x6m Modular unit is basic size for storage and larger than 3x6m may adapt value
7. Modular unit installation starts when modular unit is arrived
8. Produced modular unit will keep at storage or shipping
9. Modular unit location of storage is not considered
10. Required material supply chain is not considered

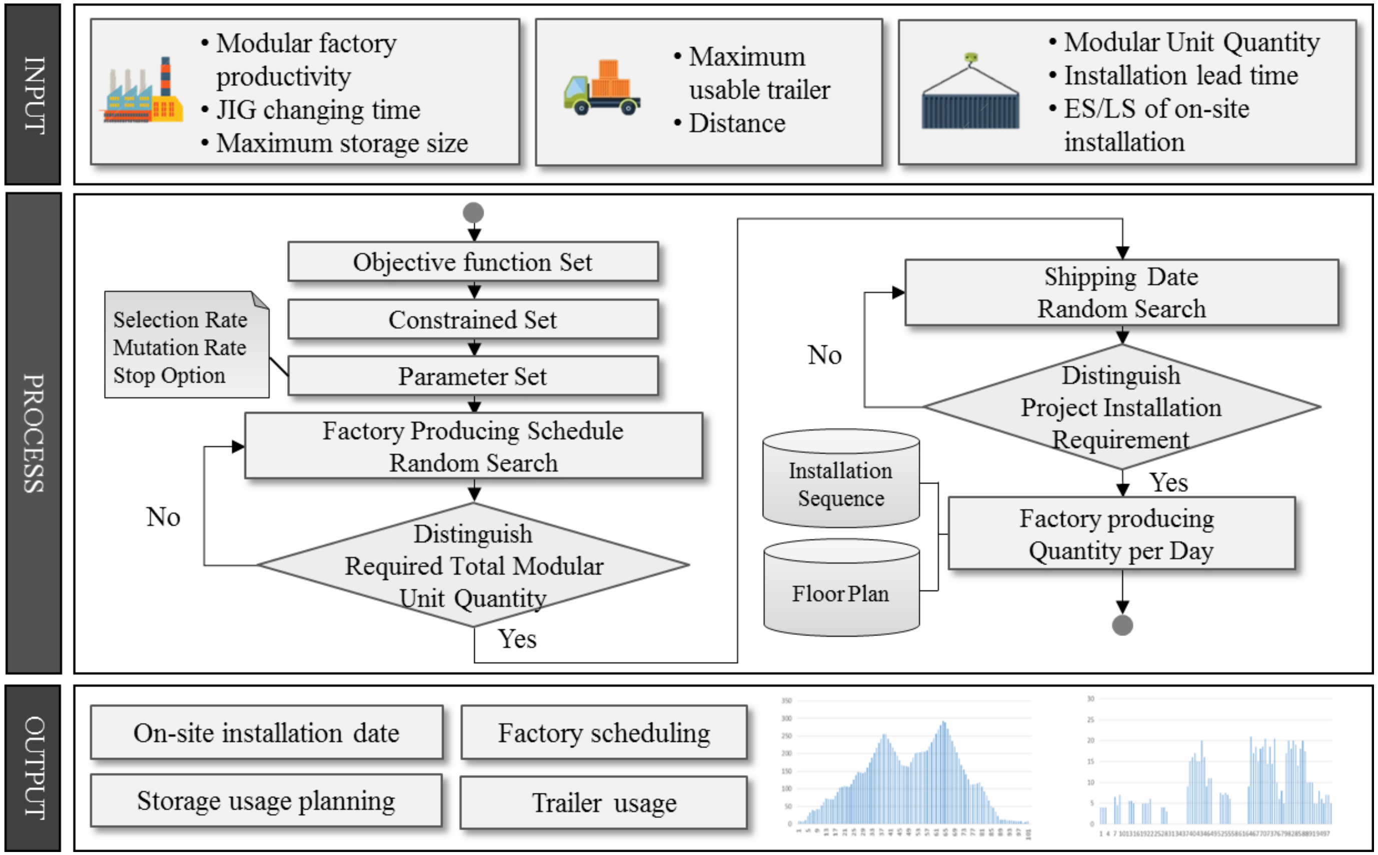

Figure 3-3 Process of Model

3.3 Summary

This chapter describes what kinds of variables are influenced to modular construction scheduling. Those variables are derived from modular construction experts and literature review. Factors can be classified with process of modular construction, factory production, transportation and on-site construction. For factory, productivity, sequence of production and storage yard size is influenced to scheduling. At transportation process, trailer and transit time from factory to site is selected as variables. On construction process, duration, erection sequence, modular unit type, number of workers on site and modular unit quantity give impact on modular construction scheduling.

With those variables, this research made a model for optimization of modular construction scheduling for modular unit factory. The objective function of the model is minimizing usage of storage yard. There are some assumptions for model.

Chapter 4. Case Study

In order to verify the optimization model of the multi project modular factory production proposed in the present study, the Department of Defense barracks project that took place in 2013 was selected as a case study. Architectural overview of the project is as Table 4-1. This is multi project, which transport modular units to the 13 sites. The location of each site is shown Fig. 4-1. All of the modular units to be transported to 13 the field is produced in a single modular unit factory in Hwa-sung. The construction period was performed in six months.

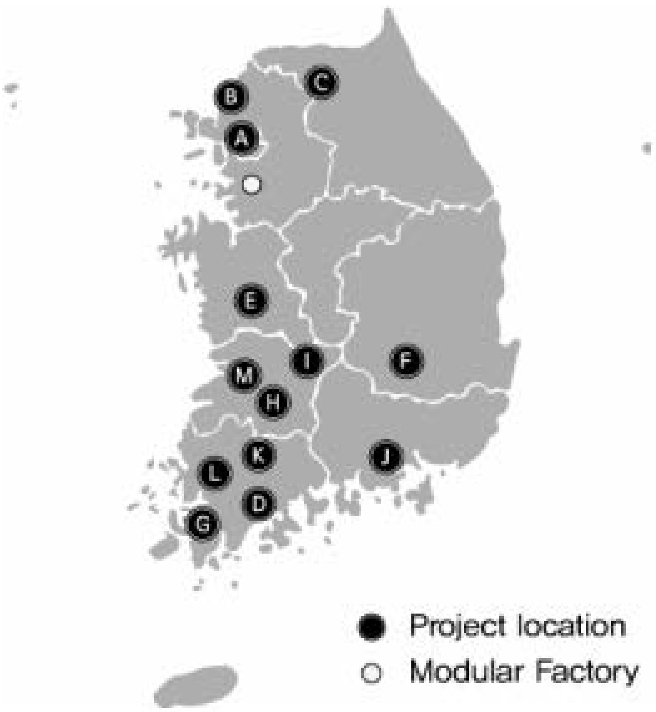

Figure 4-1 Multi Project and Factory Location

Table 4-1 Case Study Construction Outline

Section	Contents
Title of the project	‘12 Military Barracks (Modular Construction)
Duration	2013. 06. 24 ~ 2013. 12. 21.
Total Cost	27.31 Billion dollars (Exclude VAT)
Client	Defense Intelligence Agency
Architect	Haenglim Architecture & Engineering CO.
Location	Seoul Gwanak-gu Namhyun-dong 663 and 12 sites
Site	53,779.0 m^2
Principal use	Military facilities
Structure	Steel frame construction (Modular construction)
Number of stories	1~3 Stories (Maximum height : 13.2M)
Modular unit Quantity	3x6m 445 EA 3x9m 550 EA / Total 995 EA

To verify the results of case study, analyze the existing plan that was used in this multi project and compare with the optimized factory production scheduling output from the model by applying a given constraint resources.

4.1 Existing Production Scheduling

Existing factory production scheduling was planning a production date on the basis of project-specific modular unit number and quantity of modular unit. Each site-specific modular production work and installation date are as Table 4-2. After production required modular unit of the site L, E, D, M, J, they are stocked on a storage yard for two to three weeks before shipping according to the existing factory production scheduling. For the site E, a building divided into two parts, so it was classified into E-1 and E-2, consistent with the construction progress. The site K, A, G, I, F, C, B were performed transport of modular units immediately after production without any needs of storage yard of modular unit. In particular, the site M and I needs 168, 159 modular unit, respectively, therefore they require a lot of modular units than the other site.

Table 4-2. Modular Units Producing and Installation Plan

Site	Unit Quantity		Producing Modular unit / Day	On-site Installation
	3x6	3x9		
Site K	24	-	13/08/01 ~ 13/08/03	13/08/02
Site L	32	-	13/08/04 ~ 13/08/06	13/08/14
Site A	16	10	13/08/07 ~ 13/08/09	13/08/08
Site E-1	38	2	13/08/10 ~ 13/08/13	13/08/20
Site E-2	52	28	13/08/14 ~ 13/08/21	13/09/08
Site D	22	24	13/08/22 ~ 13/08/26	13/09/22

Site G	22	-	13/08/27 ~ 13/08/29	13/08/28
Site H	8	96	13/08/30 ~ 13/09/08	13/09/09
Site M	95	73	13/09/09 ~ 13/09/24	13/10/05
Site J	12	76	13/09/25 ~ 13/10/03	13/10/21
Site I	75	84	13/10/04 ~ 13/10/19	13/10/05
Site F	-	44	13/10/20 ~ 13/10/24	13/10/21
Site C	-	60	13/10/25 ~ 13/10/30	13/10/26
Site B	72	24	13/10/31 ~ 13/11/09	13/11/01
Total	468	521	13/08/01 ~ 13/11/09	-

It is vary by project, but average of modular unit production per day at modular unit factory is 9.79 units. Standard modular units are two for 3x6m and 3x9m sizes. Because the individual production line exists for each standard size, production process starts without any JIG changing.

4.2 Model for Factory Production Scheduling

The same resources that were used in the case study's original plan were applied to production scheduling model of multi project on factory in this study. Derived constrained resources and information that apply to genetic algorithm is as follows.

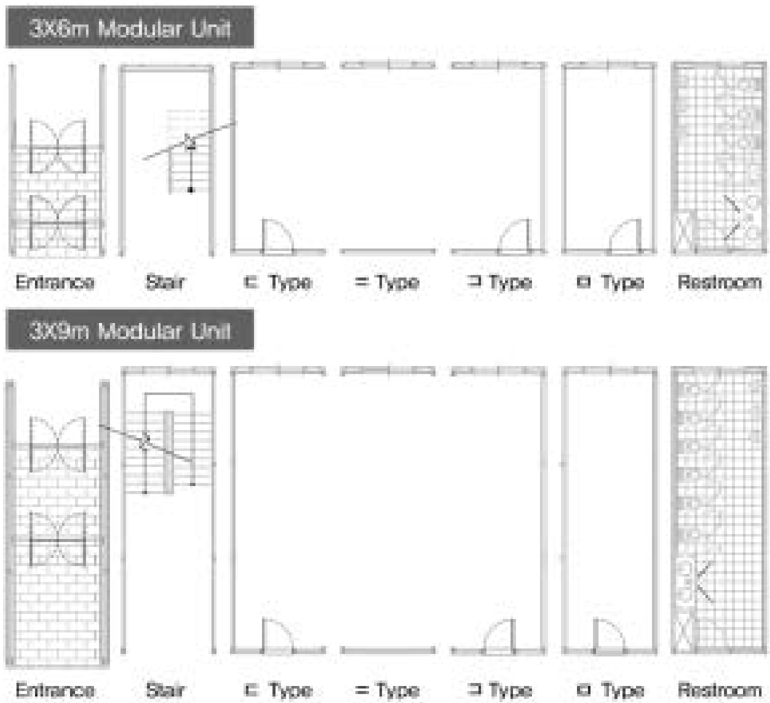

Figure 4-2 Modular Unit Type

Modular units shipped to all site can be classified into 14 types (Reference Fig. 4-2). Sizes of 3x6m and 3x9m modular units are each classified as a staircase, ㅁ type standard rooms, ㄷ type standard rooms, = type standard rooms, tiled bathrooms and entrances. This classification refers to the modular units, which can be transported to any site because of the same size and finishing conditions.

Modular factory has two production lines. Line 1 is produced a modular unit size of 3x6m and line 2 is produced a modular unit size of 3x9m. Each line can produce six modular units on one day, so it means modular units can be produced 0.75 unit per hour. Workers who are participated to produce a modular unit are set to be proportional to the size of the modular units. The sum of the production number of all day of the modular units is the same as the number of modular units, which are required to all sites. It is as follow equation (3) and (4).

$$\sum P_{i_{3X6}} = 468 \tag{3}$$

$$\sum P_{i_{3X9}} = 521 \tag{4}$$

Where, P_i : Producing Modular unit per day

In this case study, Hwa-sung modular factory can accumulate 40 modular units at storage yard, so this quantity is set to constrained set of genetic algorithm model. The storage size portion of 3x9m modular unit was set at 1.25 times of the 3x6m modular unit in consideration of the spacing of modular units. In the case of 3x6m modular unit, it can be transported two at a one time. For 3x9m modular unit can be transported one at a time because of the trailer size. Therefore, the number of modular unit transport trailer is the total value of the number of installations of 3x9m modular unit values and add up the number of installation of 3x6m modular unit divided by two. Equation (5) shows total trailer usage per day.

$$C_i = E_{i_{3x6}} \div 2 + E_{i_{3x9}} \tag{5}$$

Where, C_i : Transported Modular unit quantity per day

E_i : Installed Modular unit quantity per day

As 15 minutes of get on and off time is required for modular unit, it is possible to transport modular unit per day up to a maximum of 32. It does not take into account of on-site storage yard, so it is same as the sum of the number of installations per day, as equation (6).

$$E_{i_{3x6}} + E_{i_{3x9}} \leq 32 \tag{6}$$

A possible date of installation for each site was applied as set out in the existing plan. As a result, the modular unit transport and installation was set to start the only site where foundation work had been completed.

The number of maximum installation of modular unit per day varies depending on the each site condition and number of workers. The constraints set on minimum 1 Unit / Hour to maximum 1.75 Unit / Hour. Installation process of modular units is as Fig. 4-3. Also, after the first modular unit is transported to the project, the project is set to complete the project without any extension of the construction period in accordance with the number of modular units depending on specific site. Modular installation procedure for each project can be set based on the position of the floor plan and lifting equipment's location. The parameter values of the model are set to followings. The initial population is set to 100, crossover probability to 0.5, mutation probability to 0.1.

It is set to chromosomes that factory productivity per modular unit type and site-specific installation date. It was represented with black cell at Fig. 4-4.

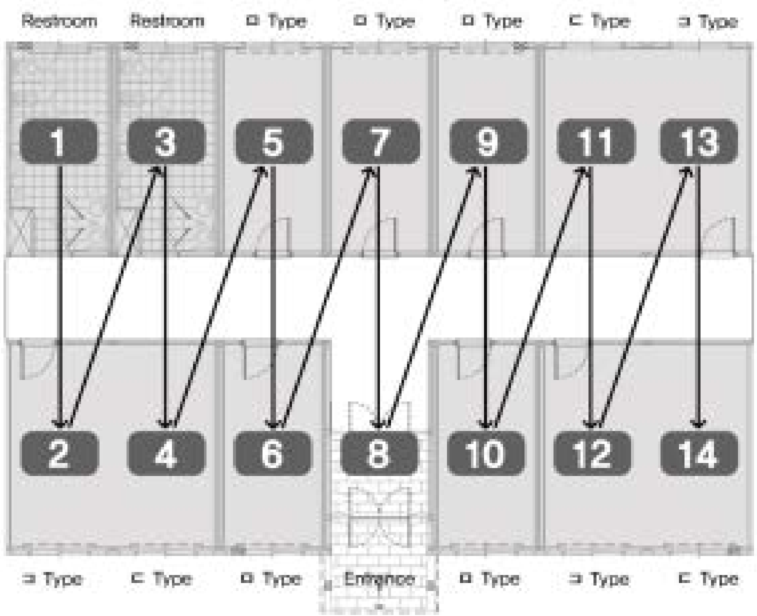

Figure 4-3 Modular Unit Installation Sequence

	Existing Plan			Factory Producing			Storage			Construction Date														
Date	3x6	3x9	Total EA	3x6	3x9	Total EA	3x6 St	3x9 St	Total St	Ship	K	L	A	E1	E2	D	G	H	M	J	I	F	C	B
2013-08-01	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-02	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-03	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-04	12	0	12	5	4	9	5	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-05	10	0	10	8	0	8	8	0	8	3	0	0	7	0	0	0	0	0	0	0	0	0	0	0
2013-08-06	10	0	10	4	4	8	3	4	8	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
2013-08-07	8	0	8	8	2	10	9	0	9	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
2013-08-08	8	0	8	8	0	8	17	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-09	0	10	10	8	0	8	25	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-10	10	0	10	9	0	9	34	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-11	10	0	10	9	0	9	43	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-12	10	0	10	8	0	8	51	0	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-13	8	2	10	9	0	9	60	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-14	10	0	10	2	8	10	51	8	61	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-15	10	0	10	0	10	10	40	18	62.5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-16	10	0	10	6	5	11	36	23	64.75	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-17	10	0	10	8	3	11	44	26	76.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-18	10	0	10	9	2	11	53	28	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-19	2	8	10	6	5	11	59	33	100.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-20	0	10	10	7	4	11	56	37	102.25	4	0	0	0	10	0	0	0	0	0	0	0	0	0	0
2013-08-21	0	10	10	7	4	11	53	41	104.25	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0
2013-08-22	10	0	10	7	4	11	50	45	106.25	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0
2013-08-23	10	0	10	5	6	11	47	49	108.25	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0
2013-08-24	2	8	10	7	4	11	54	53	120.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-25	0	10	10	6	5	11	60	58	132.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-26	0	10	10	5	6	11	65	64	145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-27	8	0	8	7	4	11	64	68	149	7	0	0	0	0	0	0	27	0	0	0	0	0	0	0
2013-08-28	8	0	8	9	2	11	65	70	152.5	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0
2013-08-29	6	0	6	10	2	12	69	72	159	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0
2013-08-30	8	0	8	8	3	11	77	65	158.25	11	0	0	0	0	0	0	0	0	0	0	61	0	0	0
2013-08-31	0	10	10	3	7	10	76	66	158.5	0	0	0	0	0	0	0	0	0	0	0	62	0	0	0

	Transport per type - 3x6								Transport per type - 3x9								Total
Date	1 [	2 =	3]	4 (	5 S	6 F	7 E	Sum	8 [	9 =	10	11	12	13	14	Sum	Transport
2013-08-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-05	0	0	0	3	2	0	0	5	1	2	0	1	0	0	0	4	6.5
2013-08-06	4	1	3	0	0	0	1	9	0	0	0	0	0	0	0	0	4.5
2013-08-07	0	0	1	0	0	0	1	2	1	4	1	0	0	0	0	6	7
2013-08-08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-14	4	2	3	0	1	0	1	11	0	0	0	0	0	0	0	0	5.5
2013-08-15	3	0	3	2	1	1	1	11	0	0	0	0	0	0	0	0	5.5
2013-08-16	2	0	3	2	2	1	0	10	0	0	0	0	0	0	0	0	5
2013-08-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-20	4	3	3	0	0	0	0	10	0	0	0	0	0	0	0	0	5
2013-08-21	1	3	2	4	0	0	0	10	0	0	0	0	0	0	0	0	5
2013-08-22	2	3	1	2	1	1	0	10	0	0	0	0	0	0	0	0	5
2013-08-23	1	1	2	0	1	2	1	8	0	0	0	0	2	0	0	2	6
2013-08-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-27	4	0	4	0	0	0	0	8	0	0	0	0	0	0	0	0	4
2013-08-28	1	0	0	4	2	0	1	8	0	0	0	0	0	0	0	0	4
2013-08-29	2	0	3	0	1	0	0	6	0	0	0	0	0	0	0	0	3
2013-08-30	0	0	0	0	0	0	0	0	2	5	2	1	0	0	0	10	10
2013-08-31	0	0	0	1	0	1	2	4	1	4	1	0	0	0	0	6	8

Figure 4-4 Production Scheduling Model on Excel

4.3 Application Results and Analysis

In the case of existing plan, it has been presenting the production scheduling on a project-by-project basis. However, production scheduling derived in this study, presents a production plan for each size of modular units required in the project. The results of model that factory production scheduling and transport start date are the same as Table 4-3. Production order of the factory that was created on the basis of the results is as Fig 4-5.

Table 4-3. Derived Modular Units Production and Installation Plan

Site	3x6 Modular Unit producing / Day	3x9 Modular Unit producing / Day	On-site Installation
Site K	13/09/26 ~ 13/10/01	-	13/09/30
Site L	13/08/06 ~ 13/08/10	-	13/08/14
Site A	13/08/04 ~ 13/08/06	13/08/04 ~ 13/08/07	13/08/05
Site E-1	13/08/10 ~ 13/08/17	13/08/14 ~ 13/08/14	13/08/20
Site E-2	13/08/30 ~ 13/09/15	13/09/01 ~ 13/09/04	13/09/08
Site D	13/09/18 ~ 13/09/25	13/09/18 ~ 13/09/22	13/09/22
Site G	13/08/17 ~ 13/08/20	-	13/08/28
Site H	13/09/15 ~ 13/09/18	13/09/04 ~ 13/09/18	13/09/09
Site M	13/10/01 ~ 13/10/16	13/09/28 ~ 13/10/12	13/10/04
Site J	13/10/17 ~ 13/10/24	13/10/12 ~ 13/10/24	13/10/17

Site I	13/08/20 ~ 13/08/30	13/08/14 ~ 13/09/01	13/09/07
Site F	-	13/09/22 ~ 13/09/27	13/09/23
Site C	-	13/10/25 ~ 13/10/31	13/10/26
Site B	13/10/26 ~ 13/11/09	13/10/26 ~ 13/11/09	13/11/01
Total	13/08/04 ~ 13/11/09	13/08/04 ~ 13/11/09	-

The start date of modular unit transport was pulled early for Site A, Site J, Site I, and Site F by 3 days, 5 days, 28 days and 28 days each. For Site K, 59 days was pulled back, other site was found to proceed in the same way as the existing plan. Site construction finish date was 7.9 percent faster overall as compared to the existing construction plans.

For existing plan, Site K produces modular unit during August 1 to August 3. However, along with this schedule, total storage usage increases, though it produces and ships modular unit at the same time. According to the model result, it is more efficient that factory does not produce the modular unit at August 1 to August 3. Therefore, pulling back construction start date of Site K could enhance efficiency of factory productivity and reducing storage usage.

Existing plan of Site M which is largest project describes that it produces all of modular units and stock at storage yard for 10 days. However, according to research output, it suggests producing and shipping almost at the same time, so it makes total storage yard usage decreases.

Site I is second largest project among 13 projects. This project’s construction start date moves early for 28 days along with model output. For producing schedule, existing plan has producing for 16 days. Model result divide schedule for 3x6 and 3x9 size module and extend producing days to 19 days. It means that model output spread productivity more consistently.

Based on existing foundation work schedule, it is found that Site I and F can be start modular construction maximum 40 days faster than existing schedule. Therefore, possible construction start duration date is extended. This makes the construction start date pull early for 28 days respectively.

By using the model developed in this study, it was found that up to 293 of modular units (3x6m modular unit basis) were stacked in storage yard on the results of analysis of the existing plan. We are able to know that modular units are stacked on the field beyond the actual size of storage yard existing at Hwa-sung modular unit factory. Through the interviews with factory officials, it was confirmed that they had rented land temporary at that time and had additional storage yard for modular units.

However, as applying the scheduling of factory production and transport derived from this model, factory’s maximum piling size can decrease to 165 modular units (3x6m modular unit basis). It can reduce the use of conventional storage usage ratio for 43%. Fig. 4-6 shows content comparing the results of the value derived from the existing plan and the model.

In addition, the rate of factory operation derived via the model shows evenly distributed per day as compared with the existing plan (Reference fig. 4-7). When preforming multi project, the existing scheduling did not reflect in conjunction with the characteristics of individual projects together. Therefore, factory’s productivity is different at the time of performing individual project.

Modular Factory Manufacturing Schedule																								
	Modular Unit Size		LINE1												LINE2									
Date	3x6	3x9	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
2013-08-04	5	4	A4	A4	A5	A5	A4								A11	A9	A9	A8						
2013-08-05	8	0	A3	A1	A1	A3	A7	A1	A3	A1														
2013-08-06	4	4	A2	A3	A7	L1									A10	A9	A9	A9						
2013-08-07	8	2	L3	L2	L2	L3	L1	L1	L7	L3					A9	A8								
2013-08-08	8	0	L5	L1	L5	L3	L6	L4	L7	L1														
2013-08-09	8	0	L3	L3	L1	L1	L4	L3	L5	L1														
2013-08-10	9	0	L4	L3	L5	L1	L6	L3	L4	E1	E3													
2013-08-11	9	0	E1	E2	E3	E3	E2	E1	E1	E2	E4													
2013-08-12	8	0	E3	E2	E4	E1	E2	E4	E3	E2														
2013-08-13	9	0	E4	E1	E2	E4	E3	E5	E4	E6	E1													
2013-08-14	2	8	E2	E2											E12	E12								
2013-08-15	0	10													I8	I10	I9	I9	I10	I9	I11	I9	I8	I9
2013-08-16	6	5	E2	E3	E1	E3	E5	E6							I9	I9	I9	I9	I10					
2013-08-17	8	3	E6	E7	G1	G3	G3	G1	G1	G3					I8	I10	I8							
2013-08-18	9	2	G3	G1	G4	G4	G7	G4	G4	G5	G1				I10	I9								
2013-08-19	6	5	G5	G3	G5	G1	G3	G3							I9	I8	I10	I8	I10					
2013-08-20	7	4	G1	I7	I6	I4	I7	I6	I4						I8	I8	I8	I10						
2013-08-21	7	4	I5	I5	I5	I5	I4	I4	I6						I10	I8	I8	I10						
2013-08-22	7	4	I7	I6	I7	I5	I4	I5	I4						I10	I8	I8	I10						
2013-08-23	5	6	I4	I6	I1	I3	I7								I10	I8	I8	I10	I10	I8				
2013-08-24	7	4	I4	I6	I4	I4	I6	I1	I3						I10	I8	I10	I8						
2013-08-25	6	5	I4	I5	I5	I5	I4	I6							I10	I8	I10	I8	I10					

Figure 4-5 Modular Unit Production Sequence Chart

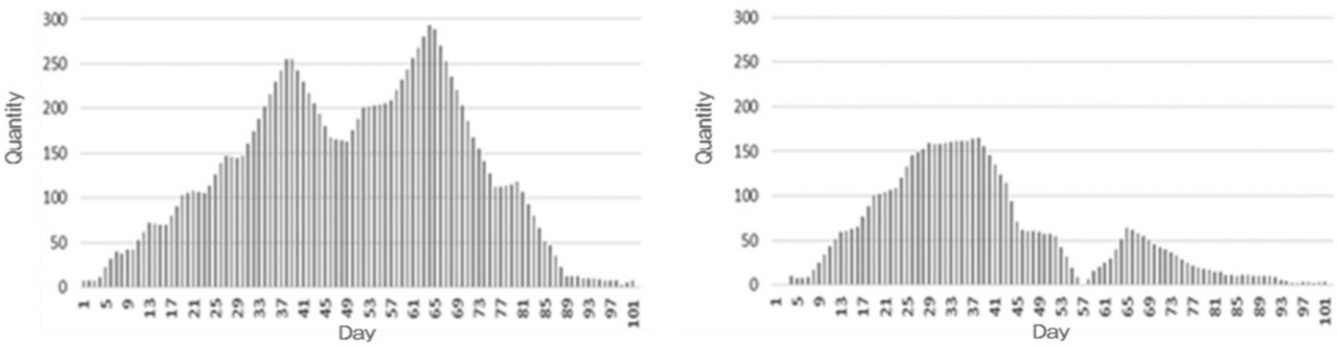

Figure 4-6 Storage Usage (Existing Plan-Left, Model Result-Right)

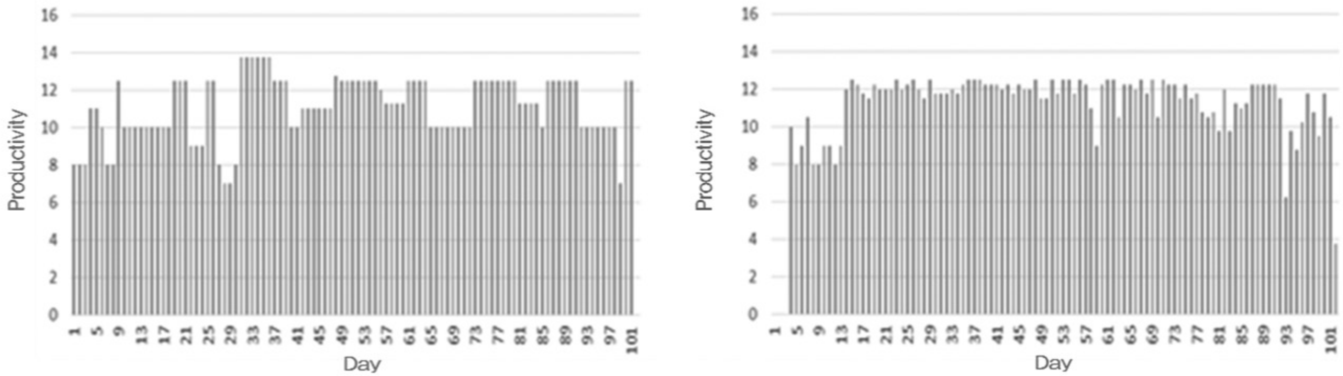

Figure 4-7 Factory Productivity (Existing Plan-Left, Model Result-Right)

4.4 Summary

In this chapter, the case study of modular construction is applied to factory production scheduling optimization model. This model has been developed to reduce the usage of storage yard by using genetic algorithm. The chromosome and constrained set are setting for case study on spreadsheet of Excel.

The case study is analyzed at section 4.1. It shows existing plan and how can it be better than before. Also, modular unit type, site location and installation sequence are described. The model results show it is possible to reduce 47% of maximum usage of storage yard of factory.

Chapter 5. Conclusion

5.1 Research Results

Modular construction has the advantage to shorten the construction time. With the increasing demand of the modular building construction, multi project is being carried out by modular factory. In this situation, modular factory takes into consideration each project’s characteristics and shared resources.

This study found the parameters related to the modular construction scheduling and presents an optimization model for modular production factory. In model, project requirement, the number of projects and size of storage yard are set for optimization. Finally optimized production schedule for factory is derived from the model. It will be more efficient for modular construction scheduling of multi project to take into account the elements which proposed in this study.

The results of this study presents that if scheduling reflects constrained of multi project, it is possible to make factory production scheduling and on-site construction period shorter compared to the existing production scheduling. It was confirmed that scheduling with derived output can reduce stacking of modular units and get uniform productivity of modular unit factory.

5.2 Contribution and Future Research

For the research scope, this paper considers not just modular factory or construction site but the process of modular construction, which covers modular factory, transport, and on-site construction. The modular unit is considered as a controllable product in terms of supply chain management.

This research proposes the application of optimization model to modular unit factory. It could be possible to reduce usage of storage yard at modular unit factory. Through this efficient production scheduling model, making continuous availability of factory productivity is also possible. If the productivity of the factory is maintained constant, it is possible to continuously charged personnel uniformly. Therefore, the factory will enable to establish a human resources planning in the certain time period.

If modular unit factory manager use the optimization model in this paper, manager can handle multi project at one time efficiently. Also, manager can schedule about which modular unit have to produce and where to shipping it, so management of modular units production and supply to on-site at multi project situation is way more efficient. Through this model, improve higher reliability of modular unit factory scheduling. Provide a modular unit producing plan and transport sequence.

However, this study did not reflect the progress of construction site. It only considers the start date of each site. Thus, this model could not reflect changing of the construction site situation immediately. Also, this research did not consider the storage yard on the site of each project, therefore research will be needed in future research for production scheduling optimization study reflects this. Future studies will be able to evolve as a study that the different kinds of project are supported as multi project.

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국 문 초 록

모듈러 건축공법은 공장 생산, 운송, 현장설치 프로세스를 통해 기존 현장중심 건축공법에 비해 품질향상 및 공기단축이 가능한 특징을 가지고 있다. 특히 모듈러 유닛의 제작과 시공이 분리되어 수행되기 때문에 다수의 프로젝트가 동시에 수행될 경우 각 프로젝트에 따라 생산해야하는 모듈의 크기, 수량, 납기일, 생산 유형 및 과정을 고려하는 SCM(Supply Chain Management) 관점의 공장 생산 공정 계획 수립이 필요하다.

그러나 현재 모듈러 유닛 공장 생산 계획은 개별 프로젝트 중심으로 수립되고 있어 다중 모듈러 건축 프로젝트 수행 시 모듈러 유닛 제작공장의 한정된 자원과 설치 현장별 프로젝트 요구조건들을 동시에 고려한 공장생산계획을 도출하는데 한계가 있다.

따라서 본 연구에서는 다양한 변수 간 상호 연계성 및 제약조건으로 공정 계획 최적화 결과 도출이 가능한 유전자 알고리즘 방법을 통해 모듈러 유닛 제작공장의 한정된 자원과 설치 현장별 요구사항이 반영된 모듈러 유닛 공장 생산 공정계획 최적화 수립 모델을 제시하며 이를 사례분석을 통해 검증하였다.

연구 결과, 기존 다중프로젝트의 공장생산계획에 비해 평균 7.9%의 현장설치 공기단축 및 43%의 야적장 이용률 감소가

가능하였다.

향후 본 연구 내용을 바탕으로 제약조건 범위 확장 및 생산성 데이터 추가가 될 경우 다중 모듈러 건축 프로젝트의 모듈러 유닛 공장 생산 계획 수립과 현장시공프로세스 구축을 동시에 지원할 수 있는 기초 자료로 활용될 수 있다.

주요어: 모듈러 건축, 모듈러 유닛, 다중 프로젝트, 공장 공정 계획, 유전자 알고리즘

학　번: 2014-20513

Master of Science in Engineering

Production Scheduling for Multi Project Modular Construction based on Genetic Algorithm

by

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Department of Architecture & Architectural Engineering

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Abstract

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The modular construction has several advantages such as high quality of product, safe work condition and short construction duration. The production scheduling of modular construction should consider time frame of factory production, transport and erection process with limited resources (e.g., modular units, transporter and workers). The production scheduling of multi modular construction project manages the modular construction's characteristics and diversity of projects, as a type of modular unit, modular unit quantities, and date for delivery. However, current modular production scheduling techniques are weak in dealing with resource interactions and each project requirement in multi modular construction project environments.

Inefficient allocation of resources during multi modular construction project may cause delays and cost overruns to construction operation. In this circumstance, this research suggests a production scheduling model for schedule optimization of multi project of modular construction, using genetic algorithm as one of the powerful method for schedule optimization with multiple constrained resources. Comparing to the result of the existed schedule of case study, setting optimized scheduling for multi project decreases the total factory production schedule. By using proposed optimization tool, efficient allocation of resource and saving project time is expected.

Keywords: Modular Construction, Modular Unit, Multi Project, Genetic Algorithm

Student Number: 2014-20513

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

This chapter presents the research background, problem statement, objective and scope in modular construction. Also, at the end of this chapter, main research process is described with research process figure.

1.1 Research Background

The modular construction is composed of modular unit production in off-site factory and erecting it on-site (Mohsen et al. 2008). A production works in a factory should be planned to take into account the schedule of on-site construction works because those two works operate at the same time. To do this, predicting the duration of modular construction process from modular unit production in factory to transportation and on-site erection is required (Alvanchi et al. 2012). In addition, it is important that the production plan of the modular factory because the modular factory supplies modular unit at multiple projects not only for one project. Modular unit quantity, required type and due date are different depending on each project. Therefore, scheduling of the modular factory is required to reflect the individual production process of each project (Noh 2005). If multi project scheduling is not well planned, saving construction duration which is strongest advantage of modular construction will not happen at the end of the construction project.

This situation could decline the project profits.

On the other hand, current scheduling method of the modular factory is same as a way that is used in the general construction industry. Compared with general construction projects, modular construction is characterized by cyclic activities that require complicated analysis (Mansooreh Moghadam, 2012). However, the traditional way does not well reflect of space allocation and repetitive tasks which are essential for the modular construction scheduling (Harris 2006; Hosein Taghaddos et al. 2010). As a result, the current scheduling is inefficient for the resource allocation of modular construction. For example, on-site work was delayed by incorrect modular unit order of installation. Owing to the lack of space for modular unit storage, factory production line was halted (Kang 2007).

Researchers have conducted a study to develop a scheduling of modular construction efficiently. However, research of modular construction scheduling mainly focuses on the scheduling optimization on a certain site (Hammad et al. 2008; Mohsen et al. 2008). As considering the growing demands for modular construction buildings, modular factory production and ships modular units on multiple projects. In this circumstance, it is difficult to implement scheduling optimization method in practice. Therefore, multi project scheduling of modular construction have to reflect characteristics of the individual projects as the overall process of factory production, shipping and erection of modular units.

1.2 Research Objective

From many research, traditional modular production scheduling techniques are weak in dealing with resource interactions in multi project resource-constrained scheduling environments. Existing scheduling tools are designed to support mainly typical construction, without considering modular building's specific needs. (Mansooreh et al. 2012)

Overlooked trailer size and installation sequence were delaying onsite construction. Because of lack of storage space, factory producing line was stopped (Kang 2008). If multi project scheduling is not well planned, this could be made decline the profits of the project.

The objective of this research is to develop optimization model for modular unit factory. First, this paper is to define variables of required resources for multi project scheduling of modular construction from literature reviews and expert interviews. The results can be utilized as a basis for optimized schedule of multi project of modular construction considering factory, shipping and erection process. Through this research, we can understand critical activities of modular construction production scheduling and constrained resources. As final result, this paper develops production scheduling model that can be used to provide optimum schedule for factory manager on multi project environment of modular construction.

1.3 Research Methodology and Scope

This research present a model that possibly plans the modular factory production scheduling related with factory, transportation and on-site installation. For the research scope, exclude on site construction scheduling, (Ex, excavation, foundation work) of modular construction process. Also suppose the modular units are using same factory production line and same kind of type.

In case of Korea, Ministry of national defense has been ordered military facilities, barracks and bachelor officers' quarters as multi project modular construction. In this paper, like those orders, confine research scope for multi project of the same type of project.

To solve the problem and to accomplish the objectives written above, this research should have the process. The research process is described at this lower page and illustrated as follow.

1) Analyzing existing problems of modular construction factory scheduling when they support multi project and selecting research methodology to solve the problem
2) Research about Genetic Algorithm as an optimization methodology and suggest apply method for this research
3) Finding out variables which reflect modular construction factory scheduling during modular unit production, transportation and on-site construction process when support multi project

4) Developing modular construction factory production scheduling optimization model with genetic algorithm based on the selected variables

5) Using optimization model, the effectiveness of the scheduling model is verified through case study and analyzing model output

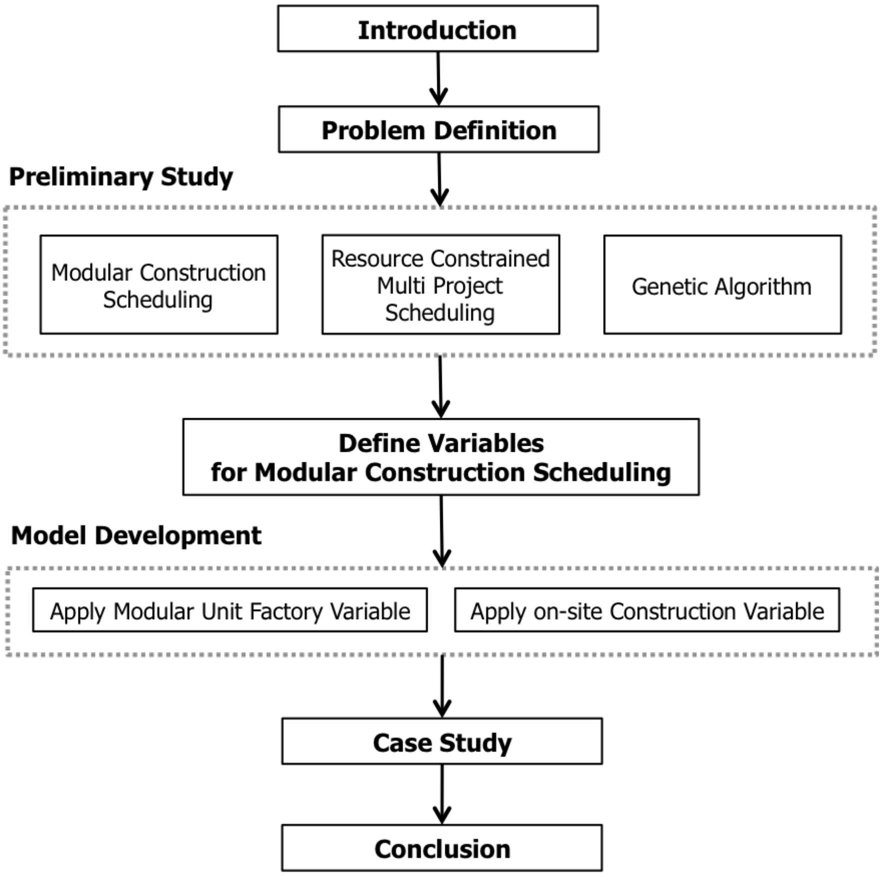

Figure 1-1. Research Process

Chapter 2. Literature Review

This chapter carries out the preliminary research for selecting methodology of research. At first, advantages of the modular construction and process of construction are introduced. Then literature review of modular construction scheduling and resource constrained scheduling is conducted. Also, limitations of previous research are discussed. Next, this study determines which optimal methods are adequate for the research. Lastly, the basic principle of genetic algorithm is described and applying process is presented.

2.1 Characteristics on Modular Construction

Modular construction is part of industrialization construction, which is construction method to install and assemble modular units (Lawson 2008). Modular unit is a structure which makes one solid space composed of three dimensions. Each modular unit is produced in modular construction factory. It has component of floor, wall, mechanical, electrical and finishing. Modular unit is designed at architecture firm, produced at factory and installed on-site (Kim et al. 2013).

Different from general construction, modular construction can minimize construction duration through factory production and on-site installation (Kim et al. 2014). Also, modular construction can get continuous quality of modular unit, mass production is possible through repetitive works (Kim and Lee 2014). When doing on-site construction, using connection place and bolt for binding point of modular units can make it reusable to dissembling. Based on those advantages, modular construction is used at military, education facilities and housing which has repetitive plan. Fig 2-1 describes modular construction process.

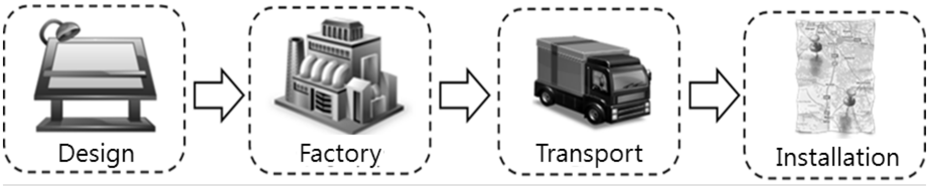

Figure 2-1. Modular Construction Process

2.2 Multi Project Factory Production Scheduling

According to the Mansooreh (2012), the scheduling method of modular construction is same as traditional construction industry. Scheduling of traditional construction is used to predict total duration based on activities' duration time and precedence relation (Kim 2014). However, constrained resource is different when performing multi project of modular construction and typical construction projects to apply the scheduling method in the same way. For the typical construction project, resource is managed by each site without sharing. However, in the case of modular construction, modular units which are produced in one factory support multi project. Thus, modular projects that are carried out simultaneously share the resources of the modular factory (e.g, modular unit productivity, workers, storage yard).

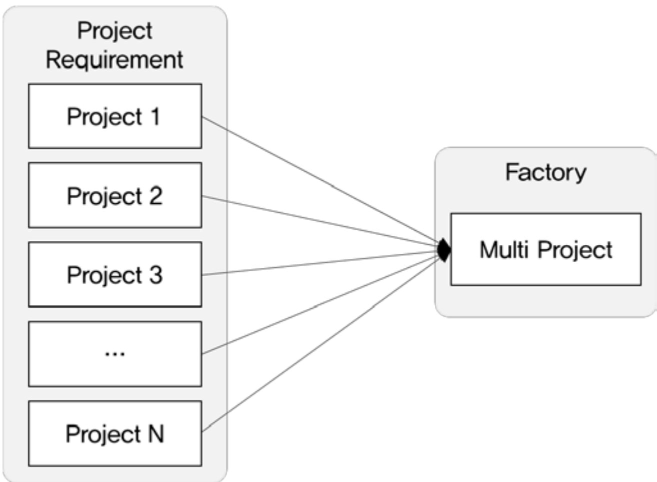

Figure 2-2. Multi Project of Modular Construction Concept

Fig. 2-2 is a diagram of multi project on a modular construction. First, modular unit production factory gathers the information of the individual projects. After that, establishing a comprehensive scheduling based on that information and provide to each project. Therefore, when scheduling a factory production process of a modular construction, it needs to consider the requirements of each project in addition to the limited resources.

When scheduling modular construction, not only the allocation of resource, but also the requirements of each project should be considered. Modular units are to be shipped on the date determined in accordance with the client request and on-site installation progress (H. Taghaddos et al. 2009). In addition, each modular unit's on-site installation sequence is fixed. Next modular unit cannot proceed with the installation, before prior modular unit installation is finished.

However, previous research about scheduling on modular construction mainly focused on the scheduling optimization on a particular site (Hammad et al. 2008; Mohsen et al. 2008). Therefore, research about multi project scheduling of modular construction is relatively insufficient.

In addition, the most research of modular construction scheduling is focused on optimizing factory production of modular unit (Jeong et al. 2006; Nasereddin et al. 2007; Yu et al. 2007; Hammad et al. 2008). A simulation model was proposed to improve the efficiency of on-site modular construction using a discrete event simulation (Mohsen et al. 2008). However, there is a limitation that previous studies did not handle the overall process, factory producing, shipping and installation of on-site.

Traditional modular construction scheduling assumes unlimited resources (Odeh 1992; Wang 2006; Kim 2007) and is inefficient to reflect repetitive activities (Harris 2006; Kim 2007). Therefore, the existing methods are not effective to reflect the constrained resources required by the modular construction. In addition, it is difficult to optimize the resources and the due date (Mohamed et al. 2007). The re-schedule due to the scarcity of resources or delay is difficult (Hosein 2014), so efficient way to schedule modular construction of multi project is required.

2.3 Previous Studies for Multi Project Scheduling

According to Payne (1995), 90% of business projects are in the context of multiple projects. Projects are planned individually and share limited resources. Modular construction scheduling of multi project should also be based on the constrained resources (Resource Constrained Multi Project Scheduling Problem; RCMPSP)

RCMPSP has been studied by a variety of methods. Methodologies which have been researched are exact method, heuristic method and meta-heuristic method.

The numerical approach is classified into linear programming (Kelly and Walker 1595), Integer programming (Meyer and Shaffer 1963) and dynamic programming (Robinson 1975). Those are local search technique to find optima output. However, it is difficult to have derived the optimal solution to handle the scheduling problem of large-scale (Deckero et al. 1991; Oguz and Bala 1994). In addition, construction managers do not bother to learn the mathematical knowledge in order to use this method (Vincent 2009).

A heuristic method determines principle of scheduling through certain criteria. This method has less computational element, so it is simple to handle. But it provides near-optimal solution and does not present a solution in alternative ways (Kumanan et al. 2006; Goncalves et al. 2008).

Meta-heuristic method which has been popular recently has a genetic algorithm as a representative method. The Genetic algorithm is widely used in practice related to the scheduling problem because it is easy to implement and highly reliable (Seren Tasan 2008). In particular, genetic algorithm in RCMPSP has been recognized for its efficiency (M. Gen et al. 2008).

Optimizing scheduling of multi project has been studied in factory production, shipping and construction industry. Meanwhile, modular construction needs a different approach from previous research because factory production and on-site construction are mixed in modular construction.

Modular unit factory production scheduling has many influence factors through modular production, transportation and installation process. Therefore, genetic algorithm could be effectively using for optimizing multiple variables on this paper.

Table 2-1 Methodology for Optimization

Methodology	Researcher	Contents
Mathematical approaches	Monhanthy and Siddiq 1989; Vercellis 1994	- Use to find the optimal solution in the local search area - Applicable to small-size problems - Few construction manager are trained to obtain the required mathematical knowledge - None of these procedures can be used for solving large-sized realistic projects
Heuristic techniques	Kumanan et al. 2006; Goncalves et al. 2008	- Rule is set based on experts opinion - Easy to apply and involve less computations - Do not provide a pool of the possible solutions according to different scenarios - only offer near-optimal solutions
Meta Heuristic techniques	Seren Tasan 2008; M. Gen et al. 2008	- Problem-independent techniques to find optimal solution - For scheduling problem, it is relatively easy to apply and highly reliable

2.4 Genetic Algorithm

A genetic algorithm is search algorithm to apply the principles of evolutionary to solve the optimization problem. This method applies nature world's evolutionary process that the most appropriate objects are only survived to engineering algorithm (J. Holland 1992). Since Genetic algorithm introduced by John Holland in 1975, it has been actively applied to transportation problem, traveling salesman problem, optimization combination problem, scheduling issues.

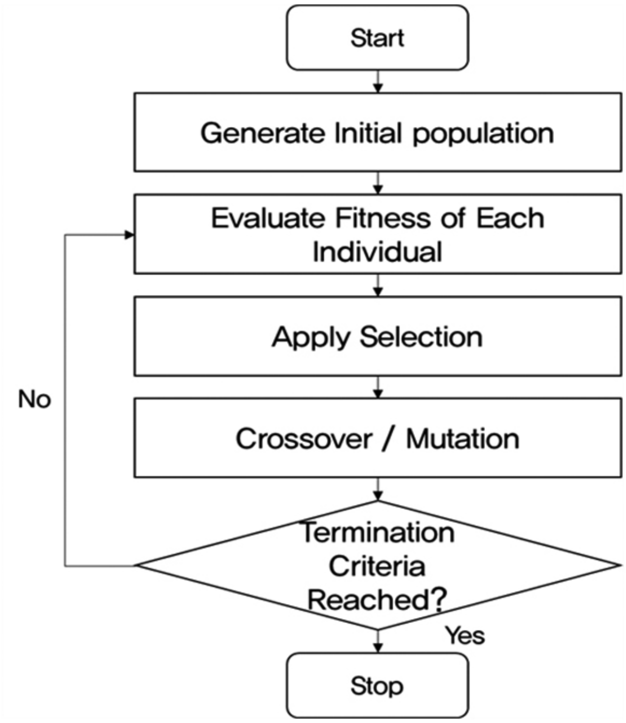

Fig. 2-3. Genetic Algorithm Flow Chart (Gilberto C. 2013)

Fig.2-3 is problem solve process of genetic algorithm. First, considering applicability of function, set genetic algorithm’s form to effectively solve the problem. Second, set the parameter values (crossover value, population size, mutation value, stop option) which give great influence to output quality and time. Third, generate initial population depend random probability. Object which follow those steps has to select by require function and constrained (Kim 2004). Finally, selection, crossover and mutation function which are standard function of genetic algorithm will start. Crossover operator create two new generation to change some of their part depend on set crossover value. Mutation changes some part as totally new one, so it prevents to converge at some point. Each combination of chromosome is to replace each other genetic information according to the probability value, and creates a new object to derive an optimum value by the stop condition.

2.5 Summary

As a part of preliminary research, the modular construction method is introduced at 2.1. There are distinguishing characteristics compared with general construction. In section 2.2, literature review on modular construction scheduling and describe the concept of multi project on modular construction. Literature review on resource constrained multi project scheduling problem is analyzed by optimization method. Through this review, this paper chooses the genetic algorithm for optimization tool, because the research has lots of variables and constrained set to optimize. In section 2.4, the basic principle of genetic algorithm and process are described.

Chapter 3. Production Scheduling Optimization Model

This chapter defined influence factors for multi project modular construction. Through influence factors, develop the model for optimization modular unit factory production scheduling.

3.1 Variables for Multi Project Modular Construction

In this study, for the construction of the factory production scheduling optimization model that utilizes a genetic algorithm, analysis of the factors that influence into the status of multi project in the production scheduling of the modular unit factory has to be preceded. It has been derived through the previous studies and expert advisory that the influencing factors of multi project modular construction. Expert discussion and interview was conducted with six practical experts at two companies of modular construction factory in November 2014 and February 2015. Contents to organize this are as Table 3-1.

Table 3-1 Impact Factors of Multi Project Modular Construction

Variable		Relationship
Factory	Productivity of factory	- Productivity is different depending on modular unit type and number of workers - Scheduling has to reflect each productivity
	A sequence of producing modular unit	- Productivity is different depending on modular unit type and number of workers
	Storage yard	- Size of storage yard affects to scheduling of shipping
Transport	Number of Trailer	- Number of trailers for modular unit transport per day
	Transit Time (Limited speed, Distance)	- Calculate with distance from factory to site and limited speed - When performing multi project of modular construction, distance to the site will be different with each project
Construction	Duration	- Construction must be done by due date of owner's request
	Erection Sequence of on-site construction	- Factory producing sequence is affected by the installation sequence of on-site construction
	Modular unit type	- Depending on the modular unit type, required installation time is different
	Number of workers	- Calculating constructability of on-site installation based on workers
	Modular unit quantity	- Depending on the project size, required quantity of modular units are different

This study analyzed the factors affecting modular construction scheduling of multi project for genetic algorithm methodology. Impact factors of modular construction scheduling are defined as follows, according to modular building construction process through analysis of previous studies and expert advice.

3.2.1 Modular Factory

In case of multi project, the factory production sequence is closely related to the factory shipping schedule that which modular unit will be transported to which site. The factor production sequence is not always exactly same as shipping schedule. It needs to consider the productivity of modular unit in the factory, the size of storage yard of modular units, and actual construction site assembling sequence (Park 2007; Abu Hammad et al. 2008).

Even if all of modular units are produced in the same factory production line, the productivity of each type is calculated differently depending on the type and size of modular units. For example, if modular unit size is larger, more workers are required or more time is spent. Also, if modular unit size is changed from 3x6m to 3x9m, factory spends sometimes on preparation for changing of modular unit size. Once producing modular units is completed, these modular units are moved to the storage yard in the factory. The storage yard is an open space for modular units, which is kept it before shipping. Number of modular units which are contained by storage yard is depending on the size of the storage yard. The modular units are staking in a storage yard in accordance with size of storage yard and on-site construction sequence. If modular units need cure the concreted surface, keep it in the storage yard. If not or the storage yard is full, modular units could ship to the site without staking in a storage yard.

3.2.2 Shipping of modular units

The modular unit, which is ready to transport, is loaded on trailer depending on their size and weight (Kim et al. 2014). The maximum number of modular units which can be transported in a day are set in consideration of the transit time from factory to site and maximum usable number of trailers per day (Park 2007; Mansooreh et al. 2012). Loading the modular unit is going to be in a state of ensuring the safety of the modular unit, and the modular unit is packaged not to be affected by rainfall. A trailer which loads modular unit should be transported in compliance with the limited speed for their safety. Arrived modular units are inspected of material condition and dropped off on the site or erected directly from the trailer.

3.2.3 On-site construction

The on-site installation of modular unit is initiated from the steps that you can assemble the modular units after the foundation work is done on site. The number of required modular units of project is different because each project size is different. Each project plan is different, so installation sequence is different from the project (M. Mohsen et al. 2008). Each site establishes a construction schedule based on the number of modular unit installation per day in consideration of the ability of workers, equipment (e.g., crane) and modular unit size (Park 2007). For on-site installation, after install the first modular unit, next modular unit installation proceeds including welding between units. Depending on the project, first floor needs joint construction between the base and the modular units.

3.2 Production scheduling model Development

A process of multi project modular unit factory of production scheduling model proposed in this study is as Fig 3-3. First, based on the derived influencing factors on multi project modular unit factory, input necessary information for the factory production scheduling model. Second, by using a genetic algorithm, get the optimized production scheduling and transportation planning which satisfies factory constraints. Finally, based on the production plan and the order of installation in on-site, derive the production sequence of a modular unit at factory.

The purpose of the model proposed in this study is to optimize the factory production scheduling, while satisfying the constraints of a particular resource, factory production, transportation and on-site construction. The value to be minimized in the model is piled up modular unit quantity, which has to be reduced as much as possible. After production of modular unit, make it simultaneously transported and able to install on-site. It will reduce the total number of stocked modular unit per day and the objective function is as follow equation (1).

$$\mathrm{OC} = \mathrm{Min} \sum S_i \tag{1}$$

Where, OC: Optimal Conbination

S_i: Storage Modular unit quantity per day

Modular unit type in this study is represented by the chromosome (see Fig.3-1, 3-2), the numbers entered in each of the genes constituting the chromosomes indicates production quantity of modular units per day.

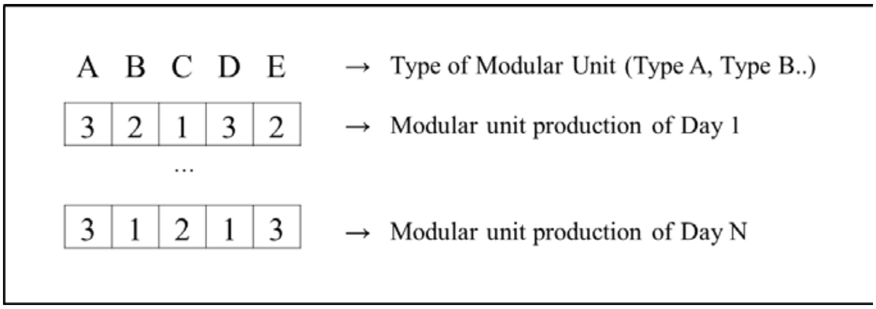

Figure 3-1 Production Unit Quantity Gene Combination

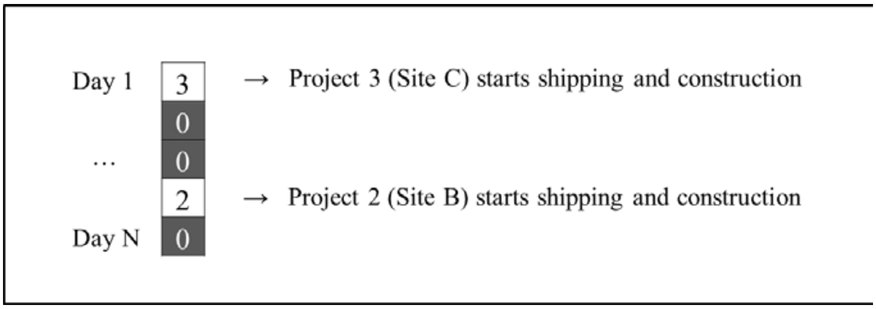

Figure 3-2 Shipping Date for Each Project Gene Combination

A combination of chromosome is increased according to the number of the required modular unit type changes JIG, the number of factory production line and the total construction period. JIG is an auxiliary equipment to fix modular unit when factory produce to make product same quality. It takes a certain amount of time to change another JIG. The combination of chromosomes, on the basis of the production volume of the modular unit per type, is object to derive production order of the modular unit factory. For example, if the numbers of individual genes are 3,1,0,0,3, A type and E type is produced quantity of three and B type is produced one. Because A, B type and E type have different modular unit size, it must be added JIG change time when producing them. Also, depending on each modular unit type, since the number of required production time or workers may vary, it is necessary to calculate the production time of the overall factory line by applying this. Daily production time was set to 8 hours. Total modular units produced at the factory are the same as the number of required units for all projects that have been determined at the time to create a factory process table.

A chromosome of Fig. 3-1, the production volume is determined to meet the requirements of each project at the time of execution of multi project. Modular unit produced at the factory, that needs to be transported in accordance with the schedule required in the field, will be set to be shipped according to the time when foundation work is completed for each site. Therefore, the modular units, which are produced prior to the transportable day, have to wait for transportation by loading the storage yard in the factory. Equation (2) shows the number of modular units that are stacked field, is a value obtained by subtracting the number of installation to the sum of the previously number of modular units that exist in the field and production modular unit on the day.

$$S_i = S_{i-1} + P_i - E_i \tag{2}$$

Where, P_i : Producing Modular unit per day

E_i : Installed Modular unit quantity per day

The modular unit to be transported to the installation site will be shipped from the storage yard in the order defined along the building plan of each project. All the modular units that are assembled in the on-site will have the information about construction time at the required site in accordance with the modular unit type. For example, construction time by modular unit type refers to the time information that how long those it take to install the case of the 3x9m modular unit or the 3x6m modular unit when the team made up of eight people works. All assumption from this model is as follows.

1. Worker's Productivity for modular unit producing is same
2. Working hours per day set 8 hour for factory and on-site
3. On-site Installation date is fixed with Early start/Late start
4. Once on-site installation starts, the site will finish the installation work with their maximum installation units per day
5. Producing Modular unit and Installation is assumed to be normal. Unexpected delay or rework is not considered
6. 3x6m Modular unit is basic size for storage and larger than 3x6m may adapt value
7. Modular unit installation starts when modular unit is arrived
8. Produced modular unit will keep at storage or shipping
9. Modular unit location of storage is not considered
10. Required material supply chain is not considered

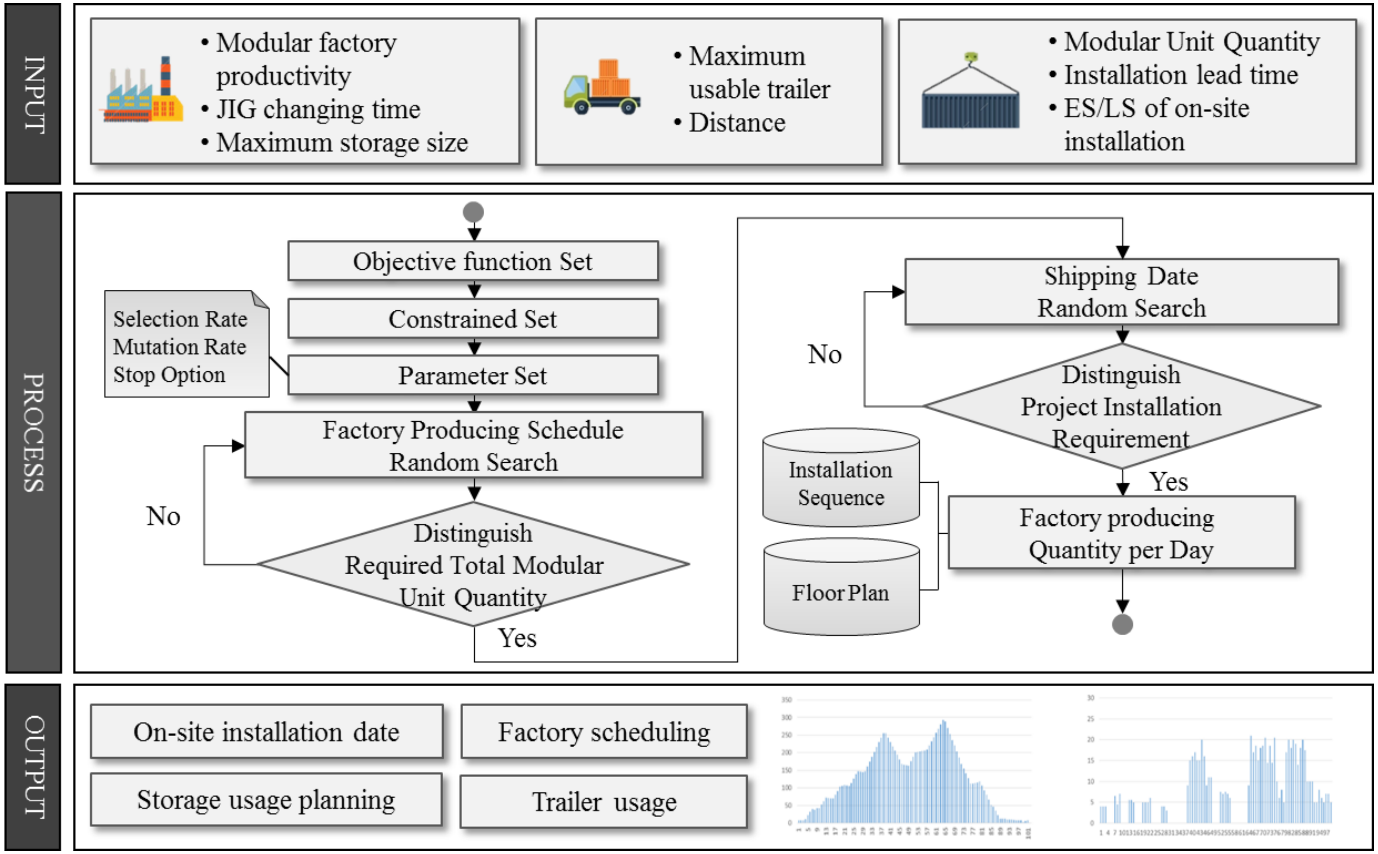

Figure 3-3 Process of Model

3.3 Summary

This chapter describes what kinds of variables are influenced to modular construction scheduling. Those variables are derived from modular construction experts and literature review. Factors can be classified with process of modular construction, factory production, transportation and on-site construction. For factory, productivity, sequence of production and storage yard size is influenced to scheduling. At transportation process, trailer and transit time from factory to site is selected as variables. On construction process, duration, erection sequence, modular unit type, number of workers on site and modular unit quantity give impact on modular construction scheduling.

With those variables, this research made a model for optimization of modular construction scheduling for modular unit factory. The objective function of the model is minimizing usage of storage yard. There are some assumptions for model.

Chapter 4. Case Study

In order to verify the optimization model of the multi project modular factory production proposed in the present study, the Department of Defense barracks project that took place in 2013 was selected as a case study. Architectural overview of the project is as Table 4-1. This is multi project, which transport modular units to the 13 sites. The location of each site is shown Fig. 4-1. All of the modular units to be transported to 13 the field is produced in a single modular unit factory in Hwa-sung. The construction period was performed in six months.

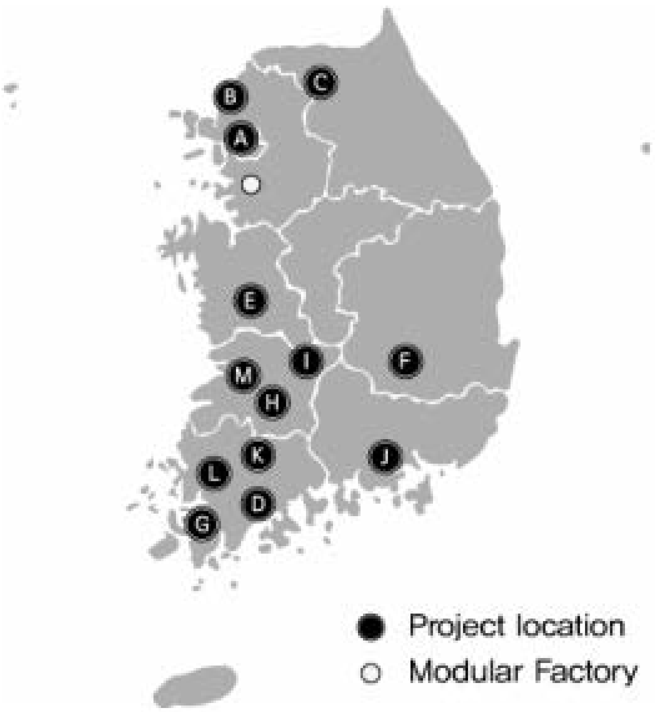

Figure 4-1 Multi Project and Factory Location

Table 4-1 Case Study Construction Outline

Section	Contents
Title of the project	‘12 Military Barracks (Modular Construction)
Duration	2013. 06. 24 ~ 2013. 12. 21.
Total Cost	27.31 Billion dollars (Exclude VAT)
Client	Defense Intelligence Agency
Architect	Haenglim Architecture & Engineering CO.
Location	Seoul Gwanak-gu Namhyun-dong 663 and 12 sites
Site	53,779.0 m^2
Principal use	Military facilities
Structure	Steel frame construction (Modular construction)
Number of stories	1~3 Stories (Maximum height : 13.2M)
Modular unit Quantity	3x6m 445 EA 3x9m 550 EA / Total 995 EA

To verify the results of case study, analyze the existing plan that was used in this multi project and compare with the optimized factory production scheduling output from the model by applying a given constraint resources.

4.1 Existing Production Scheduling

Existing factory production scheduling was planning a production date on the basis of project-specific modular unit number and quantity of modular unit. Each site-specific modular production work and installation date are as Table 4-2. After production required modular unit of the site L, E, D, M, J, they are stocked on a storage yard for two to three weeks before shipping according to the existing factory production scheduling. For the site E, a building divided into two parts, so it was classified into E-1 and E-2, consistent with the construction progress. The site K, A, G, I, F, C, B were performed transport of modular units immediately after production without any needs of storage yard of modular unit. In particular, the site M and I needs 168, 159 modular unit, respectively, therefore they require a lot of modular units than the other site.

Table 4-2. Modular Units Producing and Installation Plan

Site	Unit Quantity		Producing Modular unit / Day	On-site Installation
	3x6	3x9		
Site K	24	-	13/08/01 ~ 13/08/03	13/08/02
Site L	32	-	13/08/04 ~ 13/08/06	13/08/14
Site A	16	10	13/08/07 ~ 13/08/09	13/08/08
Site E-1	38	2	13/08/10 ~ 13/08/13	13/08/20
Site E-2	52	28	13/08/14 ~ 13/08/21	13/09/08
Site D	22	24	13/08/22 ~ 13/08/26	13/09/22

Site G	22	-	13/08/27 ~ 13/08/29	13/08/28
Site H	8	96	13/08/30 ~ 13/09/08	13/09/09
Site M	95	73	13/09/09 ~ 13/09/24	13/10/05
Site J	12	76	13/09/25 ~ 13/10/03	13/10/21
Site I	75	84	13/10/04 ~ 13/10/19	13/10/05
Site F	-	44	13/10/20 ~ 13/10/24	13/10/21
Site C	-	60	13/10/25 ~ 13/10/30	13/10/26
Site B	72	24	13/10/31 ~ 13/11/09	13/11/01
Total	468	521	13/08/01 ~ 13/11/09	-

It is vary by project, but average of modular unit production per day at modular unit factory is 9.79 units. Standard modular units are two for 3x6m and 3x9m sizes. Because the individual production line exists for each standard size, production process starts without any JIG changing.

4.2 Model for Factory Production Scheduling

The same resources that were used in the case study's original plan were applied to production scheduling model of multi project on factory in this study. Derived constrained resources and information that apply to genetic algorithm is as follows.

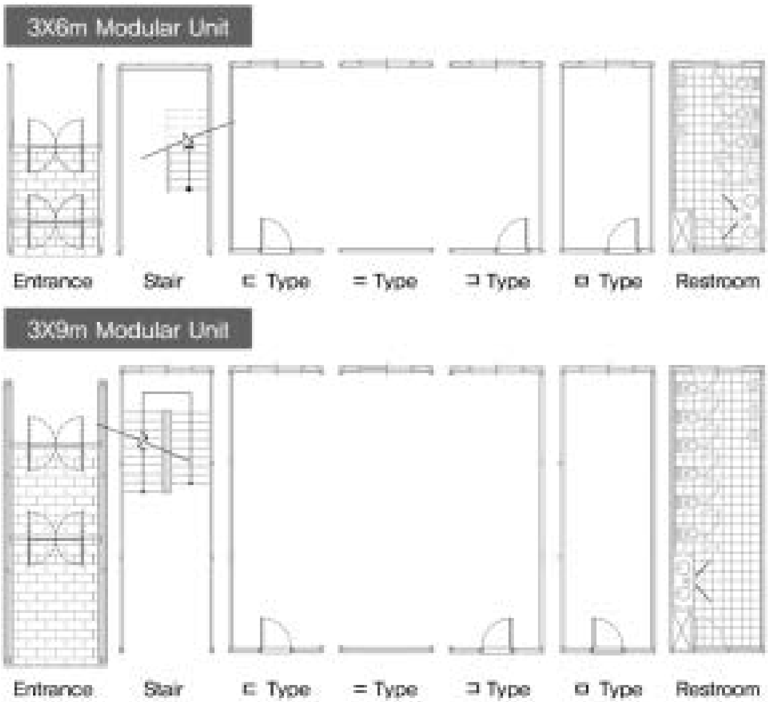

Figure 4-2 Modular Unit Type

Modular units shipped to all site can be classified into 14 types (Reference Fig. 4-2). Sizes of 3x6m and 3x9m modular units are each classified as a staircase, ㅁ type standard rooms, ㄷ type standard rooms, = type standard rooms, tiled bathrooms and entrances. This classification refers to the modular units, which can be transported to any site because of the same size and finishing conditions.

Modular factory has two production lines. Line 1 is produced a modular unit size of 3x6m and line 2 is produced a modular unit size of 3x9m. Each line can produce six modular units on one day, so it means modular units can be produced 0.75 unit per hour. Workers who are participated to produce a modular unit are set to be proportional to the size of the modular units. The sum of the production number of all day of the modular units is the same as the number of modular units, which are required to all sites. It is as follow equation (3) and (4).

$$\sum P_{i_{3X6}} = 468 \tag{3}$$

$$\sum P_{i_{3X9}} = 521 \tag{4}$$

Where, P_i : Producing Modular unit per day

In this case study, Hwa-sung modular factory can accumulate 40 modular units at storage yard, so this quantity is set to constrained set of genetic algorithm model. The storage size portion of 3x9m modular unit was set at 1.25 times of the 3x6m modular unit in consideration of the spacing of modular units. In the case of 3x6m modular unit, it can be transported two at a one time. For 3x9m modular unit can be transported one at a time because of the trailer size. Therefore, the number of modular unit transport trailer is the total value of the number of installations of 3x9m modular unit values and add up the number of installation of 3x6m modular unit divided by two. Equation (5) shows total trailer usage per day.

$$C_i = E_{i_{3x6}} \div 2 + E_{i_{3x9}} \tag{5}$$

Where, C_i : Transported Modular unit quantity per day

E_i : Installed Modular unit quantity per day

As 15 minutes of get on and off time is required for modular unit, it is possible to transport modular unit per day up to a maximum of 32. It does not take into account of on-site storage yard, so it is same as the sum of the number of installations per day, as equation (6).

$$E_{i_{3x6}} + E_{i_{3x9}} \leq 32 \tag{6}$$

A possible date of installation for each site was applied as set out in the existing plan. As a result, the modular unit transport and installation was set to start the only site where foundation work had been completed.

The number of maximum installation of modular unit per day varies depending on the each site condition and number of workers. The constraints set on minimum 1 Unit / Hour to maximum 1.75 Unit / Hour. Installation process of modular units is as Fig. 4-3. Also, after the first modular unit is transported to the project, the project is set to complete the project without any extension of the construction period in accordance with the number of modular units depending on specific site. Modular installation procedure for each project can be set based on the position of the floor plan and lifting equipment's location. The parameter values of the model are set to followings. The initial population is set to 100, crossover probability to 0.5, mutation probability to 0.1.

It is set to chromosomes that factory productivity per modular unit type and site-specific installation date. It was represented with black cell at Fig. 4-4.

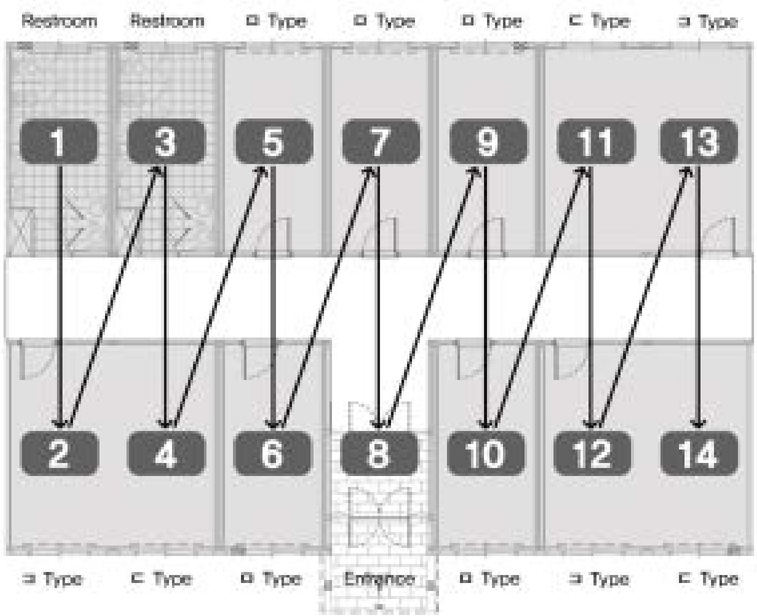

Figure 4-3 Modular Unit Installation Sequence

	Existing Plan			Factory Producing			Storage			Construction Date														
Date	3x6	3x9	Total EA	3x6	3x9	Total EA	3x6 St	3x9 St	Total St	Ship	K	L	A	E1	E2	D	G	H	M	J	I	F	C	B
2013-08-01	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-02	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-03	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-04	12	0	12	5	4	9	5	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-05	10	0	10	8	0	8	8	0	8	3	0	0	7	0	0	0	0	0	0	0	0	0	0	0
2013-08-06	10	0	10	4	4	8	3	4	8	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
2013-08-07	8	0	8	8	2	10	9	0	9	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
2013-08-08	8	0	8	8	0	8	17	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-09	0	10	10	8	0	8	25	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-10	10	0	10	9	0	9	34	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-11	10	0	10	9	0	9	43	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-12	10	0	10	8	0	8	51	0	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-13	8	2	10	9	0	9	60	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-14	10	0	10	2	8	10	51	8	61	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-15	10	0	10	0	10	10	40	18	62.5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-16	10	0	10	6	5	11	36	23	64.75	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-17	10	0	10	8	3	11	44	26	76.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-18	10	0	10	9	2	11	53	28	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-19	2	8	10	6	5	11	59	33	100.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-20	0	10	10	7	4	11	56	37	102.25	4	0	0	0	10	0	0	0	0	0	0	0	0	0	0
2013-08-21	0	10	10	7	4	11	53	41	104.25	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0
2013-08-22	10	0	10	7	4	11	50	45	106.25	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0
2013-08-23	10	0	10	5	6	11	47	49	108.25	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0
2013-08-24	2	8	10	7	4	11	54	53	120.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-25	0	10	10	6	5	11	60	58	132.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-26	0	10	10	5	6	11	65	64	145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-27	8	0	8	7	4	11	64	68	149	7	0	0	0	0	0	0	27	0	0	0	0	0	0	0
2013-08-28	8	0	8	9	2	11	65	70	152.5	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0
2013-08-29	6	0	6	10	2	12	69	72	159	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0
2013-08-30	8	0	8	8	3	11	77	65	158.25	11	0	0	0	0	0	0	0	0	0	0	61	0	0	0
2013-08-31	0	10	10	3	7	10	76	66	158.5	0	0	0	0	0	0	0	0	0	0	0	62	0	0	0

	Transport per type - 3x6								Transport per type - 3x9								Total
Date	1 [	2 =	3]	4 (	5 S	6 F	7 E	Sum	8 [	9 =	10	11	12	13	14	Sum	Transport
2013-08-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-05	0	0	0	3	2	0	0	5	1	2	0	1	0	0	0	4	6.5
2013-08-06	4	1	3	0	0	0	1	9	0	0	0	0	0	0	0	0	4.5
2013-08-07	0	0	1	0	0	0	1	2	1	4	1	0	0	0	0	6	7
2013-08-08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-14	4	2	3	0	1	0	1	11	0	0	0	0	0	0	0	0	5.5
2013-08-15	3	0	3	2	1	1	1	11	0	0	0	0	0	0	0	0	5.5
2013-08-16	2	0	3	2	2	1	0	10	0	0	0	0	0	0	0	0	5
2013-08-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-20	4	3	3	0	0	0	0	10	0	0	0	0	0	0	0	0	5
2013-08-21	1	3	2	4	0	0	0	10	0	0	0	0	0	0	0	0	5
2013-08-22	2	3	1	2	1	1	0	10	0	0	0	0	0	0	0	0	5
2013-08-23	1	1	2	0	1	2	1	8	0	0	0	0	2	0	0	2	6
2013-08-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013-08-27	4	0	4	0	0	0	0	8	0	0	0	0	0	0	0	0	4
2013-08-28	1	0	0	4	2	0	1	8	0	0	0	0	0	0	0	0	4
2013-08-29	2	0	3	0	1	0	0	6	0	0	0	0	0	0	0	0	3
2013-08-30	0	0	0	0	0	0	0	0	2	5	2	1	0	0	0	10	10
2013-08-31	0	0	0	1	0	1	2	4	1	4	1	0	0	0	0	6	8

Figure 4-4 Production Scheduling Model on Excel

4.3 Application Results and Analysis

In the case of existing plan, it has been presenting the production scheduling on a project-by-project basis. However, production scheduling derived in this study, presents a production plan for each size of modular units required in the project. The results of model that factory production scheduling and transport start date are the same as Table 4-3. Production order of the factory that was created on the basis of the results is as Fig 4-5.

Table 4-3. Derived Modular Units Production and Installation Plan

Site	3x6 Modular Unit producing / Day	3x9 Modular Unit producing / Day	On-site Installation
Site K	13/09/26 ~ 13/10/01	-	13/09/30
Site L	13/08/06 ~ 13/08/10	-	13/08/14
Site A	13/08/04 ~ 13/08/06	13/08/04 ~ 13/08/07	13/08/05
Site E-1	13/08/10 ~ 13/08/17	13/08/14 ~ 13/08/14	13/08/20
Site E-2	13/08/30 ~ 13/09/15	13/09/01 ~ 13/09/04	13/09/08
Site D	13/09/18 ~ 13/09/25	13/09/18 ~ 13/09/22	13/09/22
Site G	13/08/17 ~ 13/08/20	-	13/08/28
Site H	13/09/15 ~ 13/09/18	13/09/04 ~ 13/09/18	13/09/09
Site M	13/10/01 ~ 13/10/16	13/09/28 ~ 13/10/12	13/10/04
Site J	13/10/17 ~ 13/10/24	13/10/12 ~ 13/10/24	13/10/17

Site I	13/08/20 ~ 13/08/30	13/08/14 ~ 13/09/01	13/09/07
Site F	-	13/09/22 ~ 13/09/27	13/09/23
Site C	-	13/10/25 ~ 13/10/31	13/10/26
Site B	13/10/26 ~ 13/11/09	13/10/26 ~ 13/11/09	13/11/01
Total	13/08/04 ~ 13/11/09	13/08/04 ~ 13/11/09	-

The start date of modular unit transport was pulled early for Site A, Site J, Site I, and Site F by 3 days, 5 days, 28 days and 28 days each. For Site K, 59 days was pulled back, other site was found to proceed in the same way as the existing plan. Site construction finish date was 7.9 percent faster overall as compared to the existing construction plans.

For existing plan, Site K produces modular unit during August 1 to August 3. However, along with this schedule, total storage usage increases, though it produces and ships modular unit at the same time. According to the model result, it is more efficient that factory does not produce the modular unit at August 1 to August 3. Therefore, pulling back construction start date of Site K could enhance efficiency of factory productivity and reducing storage usage.

Existing plan of Site M which is largest project describes that it produces all of modular units and stock at storage yard for 10 days. However, according to research output, it suggests producing and shipping almost at the same time, so it makes total storage yard usage decreases.

Site I is second largest project among 13 projects. This project's construction start date moves early for 28 days along with model output. For producing schedule, existing plan has producing for 16 days. Model result divide schedule for 3x6 and 3x9 size module and extend producing days to 19 days. It means that model output spread productivity more consistently.

Based on existing foundation work schedule, it is found that Site I and F can be start modular construction maximum 40 days faster than existing schedule. Therefore, possible construction start duration date is extended. This makes the construction start date pull early for 28 days respectively.

By using the model developed in this study, it was found that up to 293 of modular units (3x6m modular unit basis) were stacked in storage yard on the results of analysis of the existing plan. We are able to know that modular units are stacked on the field beyond the actual size of storage yard existing at Hwa-sung modular unit factory. Through the interviews with factory officials, it was confirmed that they had rented land temporary at that time and had additional storage yard for modular units.

However, as applying the scheduling of factory production and transport derived from this model, factory’s maximum piling size can decrease to 165 modular units (3x6m modular unit basis). It can reduce the use of conventional storage usage ratio for 43%. Fig. 4-6 shows content comparing the results of the value derived from the existing plan and the model.

In addition, the rate of factory operation derived via the model shows evenly distributed per day as compared with the existing plan (Reference fig. 4-7). When preforming multi project, the existing scheduling did not reflect in conjunction with the characteristics of individual projects together. Therefore, factory’s productivity is different at the time of performing individual project.

Modular Factory Manufacturing Schedule																								
	Modular Unit Size		LINE1												LINE2									
Date	3x6	3x9	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
2013-08-04	5	4	A4	A4	A5	A5	A4								A11	A9	A9	A8						
2013-08-05	8	0	A3	A1	A1	A3	A7	A1	A3	A1														
2013-08-06	4	4	A2	A3	A7	L1									A10	A9	A9	A9						
2013-08-07	8	2	L3	L2	L2	L3	L1	L1	L7	L3					A9	A8								
2013-08-08	8	0	L5	L1	L5	L3	L6	L4	L7	L1														
2013-08-09	8	0	L3	L3	L1	L1	L4	L3	L5	L1														
2013-08-10	9	0	L4	L3	L5	L1	L6	L3	L4	E1	E3													
2013-08-11	9	0	E1	E2	E3	E3	E2	E1	E1	E2	E4													
2013-08-12	8	0	E3	E2	E4	E1	E2	E4	E3	E2														
2013-08-13	9	0	E4	E1	E2	E4	E3	E5	E4	E6	E1													
2013-08-14	2	8	E2	E2											E12	E12								
2013-08-15	0	10													I8	I10	I9	I9	I10	I9	I11	I9	I8	I9
2013-08-16	6	5	E2	E3	E1	E3	E5	E6							I9	I9	I9	I9	I10					
2013-08-17	8	3	E6	E7	G1	G3	G3	G1	G1	G3					I8	I10	I8							
2013-08-18	9	2	G3	G1	G4	G4	G7	G4	G4	G5	G1				I10	I9								
2013-08-19	6	5	G5	G3	G5	G1	G3	G3							I9	I8	I10	I8	I10					
2013-08-20	7	4	G1	I7	I6	I4	I7	I6	I4						I8	I8	I8	I10						
2013-08-21	7	4	I5	I5	I5	I5	I4	I4	I6						I10	I8	I8	I10						
2013-08-22	7	4	I7	I6	I7	I5	I4	I5	I4						I10	I8	I8	I10						
2013-08-23	5	6	I4	I6	I1	I3	I7								I10	I8	I8	I10	I10	I8				
2013-08-24	7	4	I4	I6	I4	I4	I6	I1	I3						I10	I8	I10	I8						
2013-08-25	6	5	I4	I5	I5	I5	I4	I6							I10	I8	I10	I8	I10					

Figure 4-5 Modular Unit Production Sequence Chart

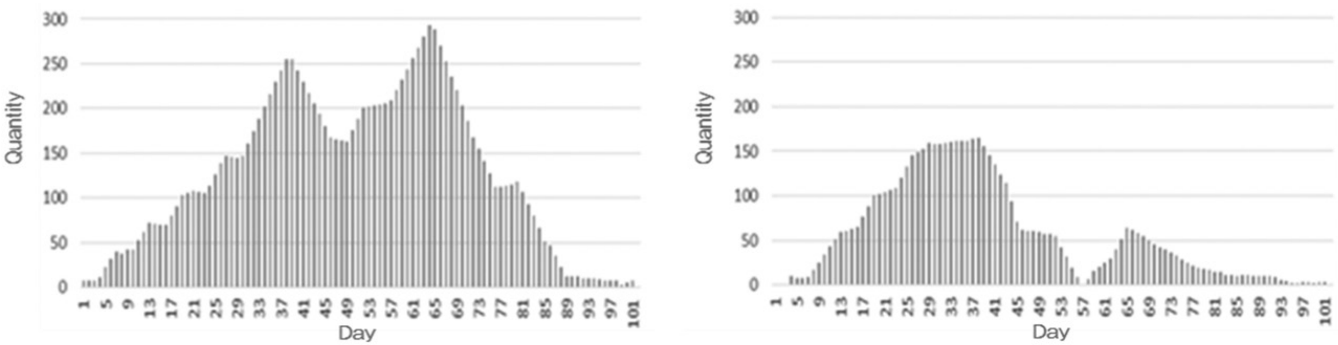

Figure 4-6 Storage Usage (Existing Plan-Left, Model Result-Right)

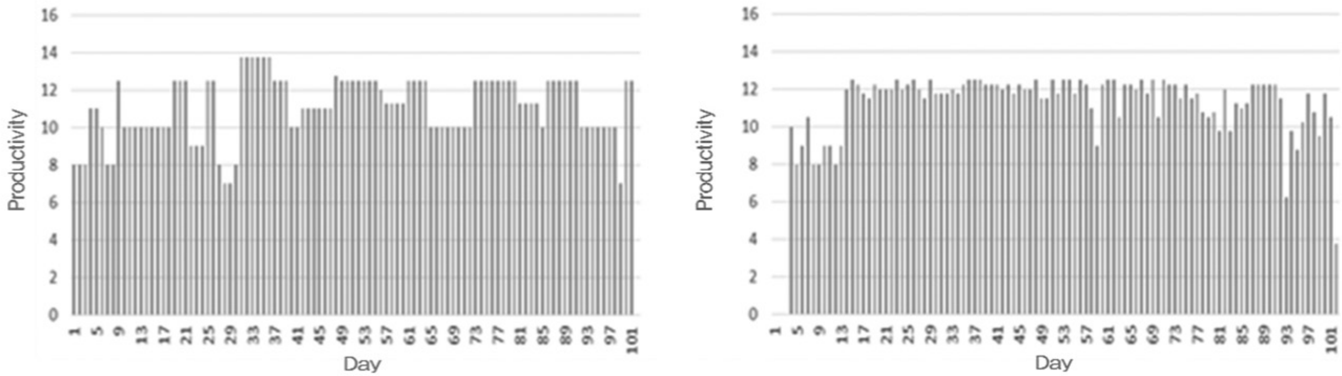

Figure 4-7 Factory Productivity (Existing Plan-Left, Model Result-Right)

4.4 Summary

In this chapter, the case study of modular construction is applied to factory production scheduling optimization model. This model has been developed to reduce the usage of storage yard by using genetic algorithm. The chromosome and constrained set are setting for case study on spreadsheet of Excel.

The case study is analyzed at section 4.1. It shows existing plan and how can it be better than before. Also, modular unit type, site location and installation sequence are described. The model results show it is possible to reduce 47% of maximum usage of storage yard of factory.

Chapter 5. Conclusion

5.1 Research Results

Modular construction has the advantage to shorten the construction time. With the increasing demand of the modular building construction, multi project is being carried out by modular factory. In this situation, modular factory takes into consideration each project's characteristics and shared resources.

This study found the parameters related to the modular construction scheduling and presents an optimization model for modular production factory. In model, project requirement, the number of projects and size of storage yard are set for optimization. Finally optimized production schedule for factory is derived from the model. It will be more efficient for modular construction scheduling of multi project to take into account the elements which proposed in this study.

The results of this study presents that if scheduling reflects constrained of multi project, it is possible to make factory production scheduling and on-site construction period shorter compared to the existing production scheduling. It was confirmed that scheduling with derived output can reduce stacking of modular units and get uniform productivity of modular unit factory.

5.2 Contribution and Future Research

For the research scope, this paper considers not just modular factory or construction site but the process of modular construction, which covers modular factory, transport, and on-site construction. The modular unit is considered as a controllable product in terms of supply chain management.

This research proposes the application of optimization model to modular unit factory. It could be possible to reduce usage of storage yard at modular unit factory. Through this efficient production scheduling model, making continuous availability of factory productivity is also possible. If the productivity of the factory is maintained constant, it is possible to continuously charged personnel uniformly. Therefore, the factory will enable to establish a human resources planning in the certain time period.

If modular unit factory manager use the optimization model in this paper, manager can handle multi project at one time efficiently. Also, manager can schedule about which modular unit have to produce and where to shipping it, so management of modular units production and supply to on-site at multi project situation is way more efficient. Through this model, improve higher reliability of modular unit factory scheduling. Provide a modular unit producing plan and transport sequence.

However, this study did not reflect the progress of construction site. It only considers the start date of each site. Thus, this model could not reflect changing of the construction site situation immediately. Also, this research did not consider the storage yard on the site of each project, therefore research will be needed in future research for production scheduling optimization study reflects this. Future studies will be able to evolve as a study that the different kinds of project are supported as multi project.

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국 문 초 록

모듈러 건축공법은 공장 생산, 운송, 현장설치 프로세스를 통해 기존 현장중심 건축공법에 비해 품질향상 및 공기단축이 가능한 특징을 가지고 있다. 특히 모듈러 유닛의 제작과 시공이 분리되어 수행되기 때문에 다수의 프로젝트가 동시에 수행될 경우 각 프로젝트에 따라 생산해야하는 모듈의 크기, 수량, 납기일, 생산 유형 및 과정을 고려하는 SCM(Supply Chain Management) 관점의 공장 생산 공정 계획 수립이 필요하다.

그러나 현재 모듈러 유닛 공장 생산 계획은 개별 프로젝트 중심으로 수립되고 있어 다중 모듈러 건축 프로젝트 수행 시 모듈러 유닛 제작공장의 한정된 자원과 설치 현장별 프로젝트 요구조건들을 동시에 고려한 공장생산계획을 도출하는데 한계가 있다.

따라서 본 연구에서는 다양한 변수 간 상호 연계성 및 제약조건으로 공정 계획 최적화 결과 도출이 가능한 유전자 알고리즘 방법을 통해 모듈러 유닛 제작공장의 한정된 자원과 설치 현장별 요구사항이 반영된 모듈러 유닛 공장 생산 공정계획 최적화 수립 모델을 제시하며 이를 사례분석을 통해 검증하였다.

연구 결과, 기존 다중프로젝트의 공장생산계획에 비해 평균 7.9%의 현장설치 공기단축 및 43%의 야적장 이용률 감소가

가능하였다.

향후 본 연구 내용을 바탕으로 제약조건 범위 확장 및 생산성 데이터 추가가 될 경우 다중 모듈러 건축 프로젝트의 모듈러 유닛 공장 생산 계획 수립과 현장시공프로세스 구축을 동시에 지원할 수 있는 기초 자료로 활용될 수 있다.

주요어: 모듈러 건축, 모듈러 유닛, 다중 프로젝트, 공장 공정 계획, 유전자 알고리즘

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