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Master of Science in Engineering

**Analyzing Work Productivity
For Modular Unit Manufacturing : Case Study**

February 2023

Department of Architecture & Architectural Engineering

The Graduate School

Seoul National University

Wooryang Jeong

**Analyzing Work Productivity
For Modular Unit Manufacturing : Case Study**

by

Wooryang Jeong

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of the requirements for the degree of
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Abstract

Analyzing Work Productivity For Modular Unit Manufacturing : Case Study

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Modular construction is expected to overcome the limitations of traditional construction methods and replace traditional construction methods with faster construction speed, eco-friendly construction methods, and safer construction methods. In addition, the modular construction market is also showing a clear growth trend accordingly. However, the proportion of modular construction methods being adopted in the actual construction industry is very low. This is because the productivity of modular factory unit production is very low. Due to the modular construction characteristics that can simultaneously carry out on-site construction and factory production, if the factory's production capacity does not keep up with the construction speed, it is directly related to the construction cost, so it is not easy to adopt the modular construction method. There has been so much research on the productivity of traditional construction methods. However, little research has been conducted on the productivity of factory workers in the manufacture of modular factories. Therefore, there is no reference data necessary to improve the unit productivity of the modular

factory. For this reason, it is still not possible to grasp for what causes the unit production line is delayed and stopped. In addition, it is not known how much work suspension or work stoppage occurs for each activity in the static production environment. Therefore, this study collects modular factory work productivity data in 1-minute units through site-observation. The collected data is classified as Activity level, and the generated idle causes are classified into Value-added Activity and Non-Value-added Activity through lean theory. We define the classified Non-Value-added Activity as a waste to be eliminated, and analyze how much waste occurred from where. Many existing studies have proposed ways to improve productivity at the macro level, such as changing the factory line or changing the schedule. However, most studies used low-rise modular data with a very short production period or traditional construction method data with different characteristics of the construction method. However, this study proposes a management plan that can improve the work productivity of factories by collecting data on middle and high-rise modular factories based on workers and eliminating waste based on this. Through this, modular construction has created basic data necessary for high-rise construction and can be used as basic data for factory managers to improve productivity of modular factories.

Keyword : Modular Construction; Modular Factory; Work Productivity; Case Study; Site Observation; Lean theory; Waste

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Table of Contents

Chapter 1. Introduction	1
1.1. Growth of Modular Construction Market	1
1.2. Low Modular Factory Productivity	4
1.3. Importance of Modular Factory Work Productivity	7
1.4. Problem Statements & Research Objectives	9
1.5. Research Framework	13
1.6. Research Scope	14
 Chapter 2. Literature Review	 17
2.1. Necessity of Modular Factory Productivity Analysis	17
2.2. Measurement of Labor Productivity	19
 Chapter 3. Analysis of Modular Factory Work	
Productivity	22
3.1. Identification of Modular Unit Manufacturing	
Activities	25
3.2. Development of Work Productivity Measurement Sheet	30
3.3. Measurement of Modular Unit Manufacturing Work	
Productivity	37
3.4. Definition of Waste in Modular Unit Manufacturing	
Based on Lean Theory	39
 Chapter 4. Case Study	 45
4.1. Case Study in Mid-to-High Rise Modular Construction	··
Projects	45

Chapter 5. Discussion	60
5.1. Discussion	60
Chapter 6. Conclusion	67
6.1. Conclusion	67
Bibliography	69
Appendices	74
1.1. Appendix A : Classification of non-work factors code	75
1.2. Appendix B : Modular Factory Work Productivity Monitoring Data	76
Abstract in Korean	95

List of Figures

Figure 1-1. Research Framework	13
Figure 1-2. Modular Factory Production Line Type	16
Figure 3-1. Modular Factory Work Productivity Monitoring Methodology Framework	24
Figure 3-2. Literature : Modular Factory Manufacturing Process	26
Figure 3-3. Expert Interview : Modular Factory Manufacturing Process	27
Figure 3-4. Hyundai Engineering Co. LTD. Expert Interview	28
Figure 3-5. Identification of Modular Unit Manufacturing Activities for Measurement about Work Productivity	31
Figure 3-6. Classification Value Added Activity and Non-Value Added Activity & Definition of Waste	44
Figure 4-1. Modular Factory Description	47
Figure 4-2. Modular Unit Production Layout in the Factory	48
Figure 4-3. Steel Material Welding	51
Figure 4-3. Material Carrying by Overhead Crane	51
Figure 4-3. Steel Structure Welding	51
Figure 4-3. Slab Rebar Placement	51
Figure 4-3. Slab Rebar Binding	51
Figure 4-3. Carrying Modular Unit Using Forklift	51
Figure 4-4. Spray on Steel Structure	52
Figure 4-4. Carrying Modular Unit on the Anchor	52
Figure 4-4. Pouring Concrete	52
Figure 4-4. Concrete Curing	52
Figure 4-4. Concrete Curing (2 days after)	52
Figure 4-4. Welding Light Weight Steel on Structure	52
Figure 4-5. Installation of Fire Resistance Gypsum	53
Figure 4-5. Installation of Stud & Runner	53

Figure 4-5. Installation of Windows & Doors Frame	53
Figure 4-5. Installation of 1 st Gypsum Board	53
Figure 4-5. Installation of Vinyl Waterproof	53
Figure 4-5. Installation of 2 nd Gypsum Board	53
Figure 4-5. Installation of Insulation	53
Figure 4-6. Installation of External Plywood	54
Figure 4-6. Installation of External Insulation & Packing	54
Figure 4-6. Carrying Modular Unit to Outside	54
Figure 4-6. Carrying Modular Unit to Outside	54
Figure 4-6. Ceiling Finishing	54
Figure 4-7. Final Work Productivity Measurement Sheet	56
Figure 4-8. Current Value Stream Map in Mid-to-High Rise Modular Unit Manufacturing	59

List of Tables

Table 2-1. Comparison of Implemented Construction Productivity Monitoring Methods	21
Table 3-1. Expert Interview's Participants Information	28
Table 3-2. Key Activities were derived Through Literature Reviews and Expert interviews	29
Table 3-3. Expert Survey Results about Activities to be Monitored Intensively	36
Table 3-4. Cause of Modular Production Idle Work (based on Literature & Mok-up Monitoring)	38
Table 3-5. Toyota Lean Production Systems "8 Wastes"	40
Table 3-6. Classification of Idle Causes based on Lean Theory	43
Table 4-1. Monitoring Project Description	46
Table 4-2. Detailed Activities by Work Productivity Monitoring	50
Table 4-3. The most low Waste Time 8 Activities per 1 Unit	58
Table 5-1. The Rate of Waste (Waste Time / Total Cycle Time)	66

Chapter 1. Introduction

1.1. Growth of Modular Construction Market

The U.S. construction industry was valued at \$1.6 trillion in 2021, and is expected to increase further in 2022. In the United States, the overall value of the construction industry increased by more than 8% between 2020 and 2021 (Modular Construction Market Size, Fortune Business Insights Reports, 2021). As such, the construction industry is still contributing greatly to the global market economy. However, it is generally classified as a less productive industry than other industries and has been lagging behind other industries such as aerospace, automotive, and shipbuilding for more than 40 years. In particular, the productivity of the manufacturing industry has doubled in nearly 20 years, while the productivity of the construction industry has continued to remain flat. In addition to the problem of productivity decline, the construction industry is facing the problem of a lack of skilled manpower (Sungjin Kim et al., 2020). AGC pointed out that it is having difficulty supplying sufficient numbers of professionals to the work site, and said it is becoming increasingly difficult to find and hire skilled workers for future construction projects. The annual rate of change in the construction industry from 2016 to 2026, related to the employment sector, is expected to be 1.2%, which closely follows the rate of change in major industries. In addition, until recently, the construction

industry has been showing a trend of continuously increasing jobs in conjunction with continuous economic growth. Considering this situation, new employment personnel and construction professionals with proficiency are needed. The demand for construction professionals continues to increase, but new professionals for construction workers, who are leaving the industry as they age, are not being added. Due to the low productivity problem of the existing construction industry and the lack of skilled workers, many construction projects are facing the problem of cost growth and time overruns (Changali et al., 2015).

To overcome key challenges facing the construction industry, such as low productivity, lack of skilled professionals, and responding to environmental regulations, the construction company is introducing a differentiated construction method that has been subjected to manufacturing processes such as modular construction. Modular construction has recently drawn attention again as a method to solve the problems of traditional construction methods such as lack of skilled workers, rising labor costs, climate change, and air delay as part of industrialized housing starting from Europe after World War II (Nam, Yoon, Kim, & Choi, 2020). The global construction market is seeking to transform itself into a factory-made construction method by breaking away from the field production method so far, and a modular construction method is emerging as an alternative. Technology is being developed around the world to improve the high-rise of modular construction and improve productivity, and in 2020, the world's highest-rise, 44-story modular house, was completed in Croydon, England (Thai, Ngo, & Uy, 2020). The global modular construction market in

2020 approached US\$72.11 billion. In particular, the impact of the COVID-19 pandemic has soared the positive demand for modular construction. The modular construction market is expected to grow from \$75.89 billion in 2021 to \$114.78 billion in 2028, with a CAGR of 6.1% (Modular Construction Market Size, Fortune Business Insights Reports, 2021). Modular construction methods are gaining huge popularity among housing conglomerates due to various advantages including waste reduction in construction sites, rapid construction, cost efficiency, and eco-friendliness. In particular, according to industry experts, modular construction projects can be completed 30 to 50 percent faster than traditional construction methods. Interest in adopting lean manufacturing technology is increasing to promote the growth of the modular construction market. Modular construction is a method that combines traditional construction methods and manufacturing methods, and can be implemented based on lean production (Goh & Goh, 2019). This type of production has the potential to significantly improve quality and productivity. It can also greatly help reduce waste and lower operating costs. Therefore, the increase in the adoption of lean production technology is expected to play a good role in the growth of the modular construction market worldwide.

1.2. Low Modular Factory Productivity

The advantages of modular construction overcoming the limitations of traditional construction methods and ideally improving them are widely introduced. However, if you look around us, it is hard to find a site that applies a modular method (Shin, J. et al., 2022). Looking at the cases where the current modular construction method is applied, it is not a common and widely used construction method, but is applied only in special cases in specific projects and is often conducted in the form of a case project. We need to solve the causes of these situations first rather than applying the modular construction method while looking only at the ideal in this situation.

Many studies have been conducted on the productivity of existing traditional construction methods. However, there are few productivity-related studies, as the studies on modular construction methods introduced to overcome the limitations of traditional construction begin with statistical data that modular construction is basically much more ideal than traditional construction methods. Then, the question arises: Is this really innovative and modular construction that can be carried out quickly, not well seen around us, and is it limited to specific projects? According to Mao et al., 2016, it was analyzed that the construction cost of the modular construction method was higher than that of the traditional construction method. In addition, when collecting opinions from a number of corporate experts who are actually conducting modular construction, we were able to derive interview answers that modular

construction is not more productive than traditional construction. The biggest advantage of modular construction is the shortening of air. This is because it is an environment where it is possible to manufacture modular units in a modular factory and at the same time, construction can be performed simultaneously on the site. In addition, unlike traditional construction methods, the modular construction method has a Make-to-Order environment in which modular units are ordered at the site and modular units are manufactured(Nadi, 2019). accordingly, so a systematic approach is needed. However, since many attempts have been made to apply the existing method rather than changing the traditional construction process to suit the modular construction environment, the construction cost of the modular construction is still higher than that of the traditional construction method.

According to interviews with 21 construction experts, although the construction speed of modular construction is certainly fast, there was an opinion that the higher the height, the more similar the speed of R/C (Posco A&C, 2021). In particular, there is a lack of experts to improve this problem because there are very few experts in modular construction compared to traditional construction experts in carrying out 13-story modular construction work. Therefore, it is difficult to determine what causes productivity to be low in the modular construction process and whether the construction cost is higher than that of conventional construction. In particular, the time to install the produced unit in the field is very fast as characteristics of the modular construction method, but it takes a long time to produce and supply the modular unit in the factory, causing a problem of productivity degradation. As

the time point at which the unit is supplied is slow, the site loses as much as the period. As a result of consulting experts with more than 13 years of experience in modular construction, there was an opinion that floor heating is essential in Korea, and construction costs increase because most of them are made of steel. However, most of the respondents said that productivity was poor within the actual production process, such as ceiling construction or other finishing works, but it was difficult to know exactly which part of the problem and how to improve it. Although modular construction methods are in the spotlight as a very ideal and future construction technology with high growth potential, there are obstacles to the spread of such modular construction methods in reality (Pan & Sidwell, 2011). Among them, the biggest problem is that the production capacity of the factory cannot keep up with the construction speed of the site, and this study attempts to deal with the problem. In order for a modular construction method to be widely used that can overcome the limitations of the existing construction method, companies must promote it, and in order for a company to gain momentum, this solution can be achieved only by improving the productivity problem of modular construction first.

1.3. Importance of Modular Factory Work Productivity

Numerous Studies focused on identifying the key factors for improvement of modular construction productivity and performed opinion-based studies, such as surveys and interviews (Jin Ouk CHOI et al., 2014; Hwang et al., 2018; Abdul Nabi et al., 2020; Abdul Nabi et al., 2022). These opinion-based findings should be accompanied by case studies in the actual field. This is because the main factors identified through these opinion-based studies are difficult to answer 'why' questions such as 'why these factors are important' and 'why this phenomenon occurs'. Modular construction projects have a very small number of projects compared to traditional construction projects, and thus involve great difficulty in collecting data from actual projects. The most important part for productivity analysis is to collect real data related to this. However, due to the difficulty of collecting actual data, most studies to improve the productivity of modular factories have only proposed macro-level management methods. In addition, several studies have been conducted in an effort to identify the causes that hinder the productivity of modular construction work, but most studies have derived the causes of inhibition at a high level at the project level (Abdul Nabi, 2022). Therefore, it is still difficult to know exactly which idle causes in the modular factory production line act as a factor that hinders productivity. Modular construction work has the characteristics of the manufacturing industry and also the characteristics of the construction industry. The construction industry has been facing the problem of a chronic decrease in labor force for a long time, and sites that apply

traditional construction methods are also suffering from a shortage of labor force. The case of modular construction is no different. In addition to the lack of experts in modular construction, modular construction work is still being carried out centered on workers.

Case studies in real-life are conducted based on the main factors affecting productivity identified through Literature Review. Based on the experiences captured through the case study, we identify the content of 'why these factors occurred' lacking in literature. The goal of this study is to identify the cause of low modular factory productivity based on the main factors affecting the productivity of the modular construction project. Then, we analyze this quantitatively. It is necessary to understand the tasks and lessons learned from the worker's activity perspective, not from a macroscopic perspective, by conducting an in-depth case study on actual modular factory production. Identify the causes that hinder actual work productivity at the activity level. Based on this, it identifies practical efforts to increase the production rate of modular factories in the future. Because the number of cases in modular construction projects is very limited, the results of surveys and interviews and case studies conducted will be very useful for modular practitioners and researchers.

1.4. Problem Statements & Research Objectives

Problem Statements

Many productivity studies on existing traditional construction methods have been conducted for a long time. It was expected that the modular construction method could solve problems such as productivity, safety, and environment, which are chronic problems of traditional construction methods, but the modular construction method has not been widely applied yet. The fact that the productivity of the modular construction method is lower or similar compared to the existing construction method is a major barrier to the spread of the modular construction method. However, little research has been conducted on the productivity analysis of the modular construction method. This is because the number of modular construction projects is very small and it is very difficult to collect the data on modular construction. In order to spread the modular construction method, data collection in the modular construction method must be preceded, productivity must be analyzed, and improvement measures must be preceded.

Many efforts have been made to find out the cause of productivity inhibition in modular construction, but research is mainly focused on deriving the cause of productivity inhibition from the perspective of the project. Therefore, due to the nature of modular construction, which is still centered on workers, it is difficult to determine exactly how much productivity is decreasing in which industry, and for this reason, modular construction companies are

also having difficulty finding ways to solve the problem of increasing construction costs. Therefore, it is necessary to establish a clear process for workers in a modular construction factory, and to understand the productivity obstacles centered on workers to what causes the productivity of the modular construction work to be impaired. This requires productivity monitoring data of modular factory workers, but data on labor productivity of modular factories is very difficult to collect due to the nature of modular projects. Since there is no data on the monitoring of labor productivity in modular factories, it is not known which engineering causes productivity degradation, and thus the production speed at which modular units are manufactured decreases.

Research Objectives

Existing studies related to the productivity of modular construction mainly focused on identifying major factors that affect the productivity of modular construction projects. And most of these studies have been conducted as opinion-based studies such as survey and expert interviews. However, these opinion-based studies cannot identify the part of why these factors occurred. Therefore, this study conducts a case study based on the main factors affecting productivity presented in the existing literature. A case study was conducted on the largest and largest modular construction project in Korea. The goal of this study is to define waste based on major productivity inhibitors and to identify why this waste occurred. In addition, we propose productivity monitoring methods to identify them and conduct monitoring to analyze how much waste is being generated.

Many studies have been conducted to analyze the causes of inhibiting modular construction productivity. However, most of the studies only identified the cause of productivity inhibition at the project level through interviews with modular experts. Therefore, it is difficult to derive a plan to improve the productivity of the factory. In addition, research on the productivity of traditional construction methods has been conducted for a long time, but research on the productivity of modular factories has rarely been studied. Although the modular construction market is expanding, it is very difficult to obtain data on modular construction projects compared to traditional construction methods. Due to the modular construction characteristics that have both the characteristics of the construction industry and the characteristics of the manufacturing industry, the production of modular factories is also carried out centering on the activities of workers. Therefore, this study monitors worker productivity at the activity level and collects labor productivity data from modular factories.

Even if the modular unit is manufactured in a factory, due to the modular construction characteristics of the construction industry, the modular unit production method is still fixed and workers move as a team to work. In addition, unit production of the modular factory is carried out mainly by workers, and accordingly, it is necessary to consider the characteristics of the modular factory in applying the lean production method. Therefore, based on the data collected through modular factory worker labor productivity monitoring, this study identifies the cause of idle and idle time of modular factory workers and classifies them according to Lean theory. Value-added activity, an activity that

actually contributes to improving productivity, and non-value-added activity that must be removed to improve productivity as a factor that hinders productivity are defined as waste and classified. Ultimately, this study aims to provide basic data for factory managers to focus on identifying factors that hinder productivity in the modular unit production process based on Lean theory.

Existing studies have suggested management measures at a macroscopic level based on data from traditional construction methods. However, this method is a method that changes the environment of the factory itself or is difficult for the factory manager to use. In addition, the higher the modular building becomes, the longer the production period of the modular factory becomes, and other problems that cannot be found in existing modular data such as changes in production speed due to workers' repetitive skills and narrowing of work space due to unit landings are derived. This study aims to provide factory managers with measures to improve productivity by identifying and classifying the causes of productivity impairment for workers defined as waste.

1.5. Research Framework

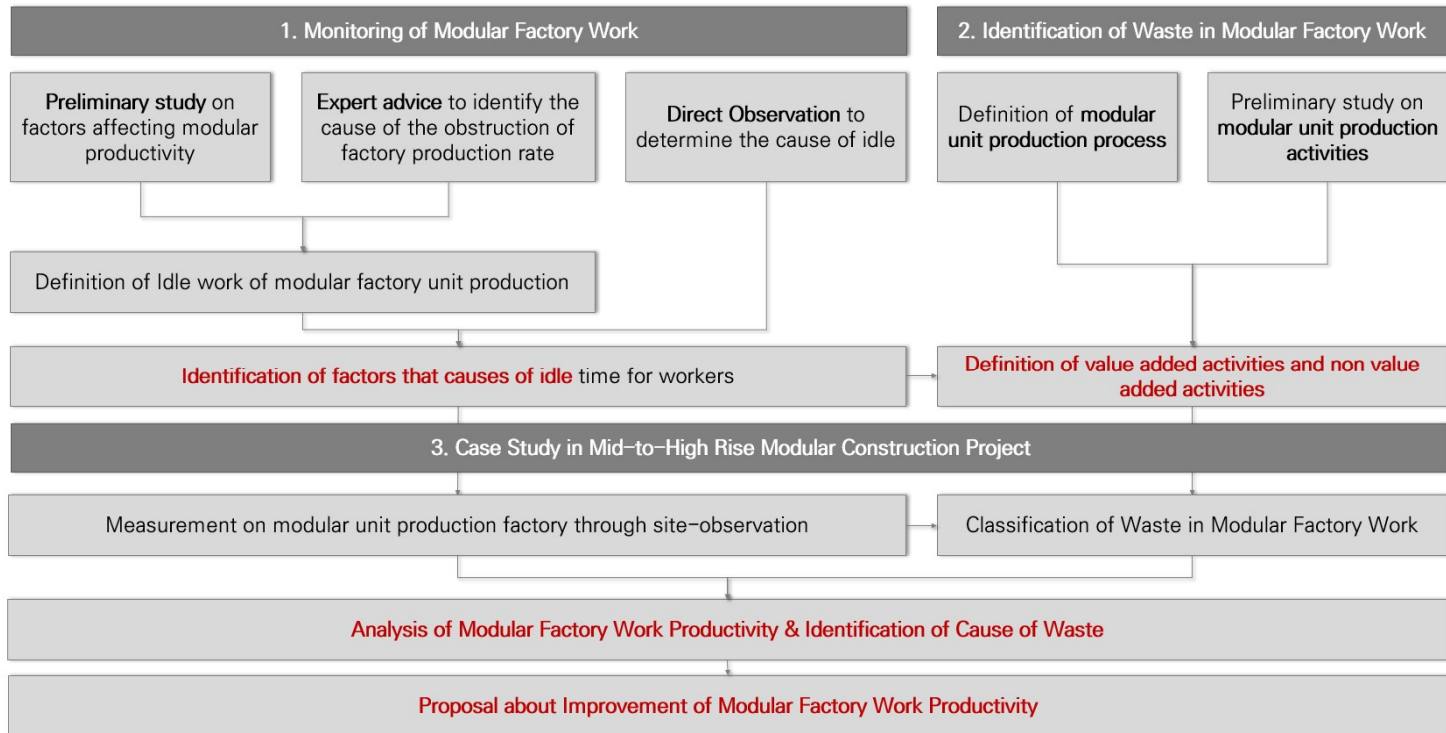


Fig 1-1. Research Framework

1.6. Research Scope

The production of modular factories is largely divided into two ways. First, the static production method, which is a method in which workers move around fixed modular units in a team while the modular unit is fixed. Second, there are two modular unit factory production lines, which are located fixed to the station and are used by the modular unit to move the station along the conveyor. Most of the existing studies insist on a continuous production method as an ideal modular unit production method. However, the purpose of the production line of the modular unit factory may also vary depending on the environment required by each modular project. In the case of the continuous production method, there is an advantage that workers only have to work in their own work area at a constant speed. In addition, the manufacturing industry is also widely adopting this working method. The advantage of this method is that it can lead to maximum productivity by completely eliminating waste that hinders productivity. However, if a problem occurs even in one part of the production line, it affects the entire production line, and there is a disadvantage that productivity decreases rapidly. In addition, there is a disadvantage that it is not possible to shorten the construction period while increasing the manpower input in a situation where the construction period must be met. In the case of the continuous production method, the worker only performs the assigned work within his or her work area, so even if additional manpower is invested, the production speed does not increase. In the case of the static production method, since it is a method in which workers work in

teams, there is a disadvantage that a lot of mobile interference can occur, which can cause work congestion(Jeong, Gilsu et al., 2022). However, there is an advantage that it can be flexibly adjusted if it is necessary to shorten the construction period. Therefore, it is necessary to establish a production line suitable for the project type in consideration of the advantages and disadvantages of each line, and only the Continuous production line cannot be the answer. In the case of continuous production lines, initial construction costs are very high, and there are no specific standards to refer to the construction of the line, so the risk of adopting the production method is avoided. In addition, since the construction industry is a project-based industry, the specificity required for each project is different. Accordingly, there is a gap difference between research results and actual field application. Until now, most modular factory producers adhere to the static production method, which prefers the static production method that can flexibly adjust the production input personnel even if the type of each project changes to achieve the final goal.

Modular construction is a method in which units are manufactured in the factory and only installed in the onsite-field, so most of the working hours are performed in the modular factory. Therefore, the scope of this study is limited to modular factories. Among them, the scope is limited to the static modular factory production Line.

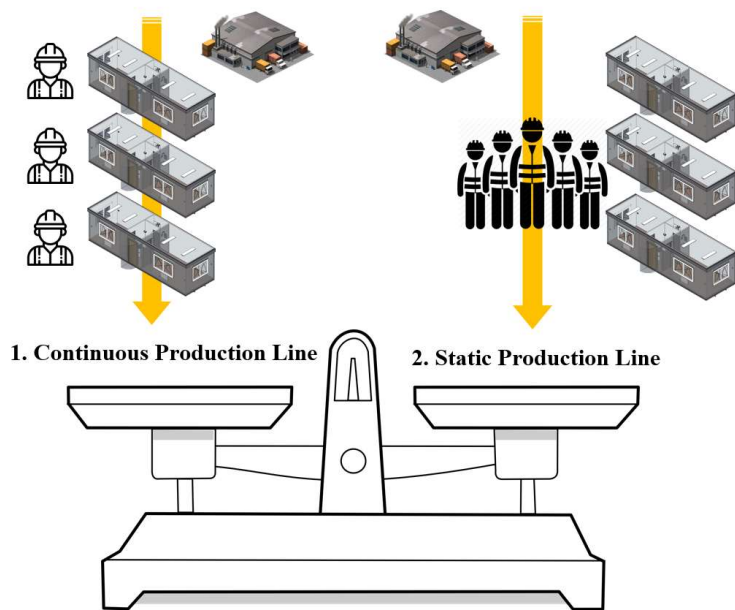


Fig 1-2. Modular Factory Production Line Type

Chapter 2. Literature Review

2.1. Necessity of Modular Factory Productivity Analysis

The modular construction method has a process of manufacturing in a factory and installing in the field. Accordingly, it has the advantages of faster production speed, better quality, safer environment, and better environment for recycling units (Hwang, S., et al., 2021). Accordingly, the modular construction method is gradually in the spotlight. However, despite the advantages of this modular construction method, it is very difficult to find a project that applies the modular construction method in the vicinity (Hong, J., et al., 2017). This is because, like the traditional construction method, the productivity of the factory is still very low due to the characteristics of the factory where the workers are centered and modular unit is manufactured (Mao et al., 2016). In order to overcome these problems, many studies have been conducted to improve the productivity of modular construction. However, since the number of modular construction projects is very small and data is difficult to collect, most studies related to modular construction productivity have only identified major influencing factors using survey or interview methods at a macro level (Jin Ouk CHOI, et al., 2014; Abdul Navi, et al., 2021). Opinion-based methods such as these surveys and interviews are difficult to answer exactly why these factors were identified (Bozorgi et al., 2018). In addition, most of these studies remain in a macroscopic approach at the project level, not at the activity level. Since

the static production method, which is a method in which workers move around each unit as a team, is mainly used in the factory manufacturing method (Jeong G., et al., 2022), productivity analysis at the activity level is needed, and efforts to improve the productivity of modular factory work are needed. Moreover, the construction cost of the modular construction method is set at a higher or similar level compared to the traditional construction method. Particularly, due to the characteristics of the modular construction method where most of the work is carried out in the factory, a lot of waste is generated in the factory work, which is being carried out due to an increase in construction costs. Therefore, it is necessary to study why some waste occurs in factory work and to identify how much waste occurs quantitatively.

2.2. Measurement of Labor Productivity

Among the strategies for improving construction work productivity, the most important method is to collect accurate and continuous work productivity data (Iqbal Noor et al., 1998). According to Wesam S. A. et al, there are various methods for measuring work productivity, and each method has advantages and disadvantages for each environment, so it is essential to select an appropriate measurement tool for the environment to measure work productivity. Using sensors has the advantage of being able to easily collect data with less labor and cost. However, due to the nature of modular construction projects with very difficult environments to collect data, raw data must be measured very accurately. The traditional method of measurement, direct observation, is expensive and time consuming because it requires measurement by a measuring person with expertise in making measurements and requires long-term residence. However, it is the most accurate of all methods, and it is a method that can cover a wide range for monitoring all activities. In addition, interference rarely occurs due to other conditions, and measurements can be made under all conditions regardless of indoor and outdoor environments. Since this direct observation measurement method requires a lot of labor and cost, it mainly uses a method of setting a measurement time interval such as FMR (Five-Minute Rating) and measuring it at each time zone (Kim, J., et al., 2022). However, the disadvantage of this method is that it is impossible to know what situation occurred during the broken section (Iqbal Noor et al., 199). Therefore, in order to overcome these limitations, a continuous ob-

servation method that can be constantly observed in each section is needed. Due to the nature of modular projects that are difficult to collect data, the most accurate and continuous measurement method is needed, and data must be collected in this way to be used as the most basic productivity data.

Method / Metrics	Range Cover	Weather Conditions	Computational Time	Required devices, Special Requirements	Intrusiveness	Accuracy	Testing Environment	Monitored Activities
Traditional Methods	Wide Range	Affected	Slow	Skilled Workers doing the survey	Non	High	Indoor - Outdoor	Formwork, Steelwork, concrete work, masonry, screed, tiling, plastering, false ceiling, curtain wall, MEP and worker activities
Computer Vision-based	Within Cameras View	Affected	Fast	Cameras	Non	High-above 90%	Outdoor	Excavation, crane cycles, concrete work, hoisting, formwork and excavation equipment
Photogrammetry	Within Cameras View	Not Affected	Fast	Cameras	Non	High-above 90%	Outdoor	Excavation operations and reinforced column
Bluetooth Low Energy	Rnage of 5-10m	Not Affected	Fast	BLE tags, Receivers, WIFI Router and monitoring device(laptop)	Intrusive	High within the covered range	Lab	Movement and location of workers
Smart Phone Sensors	Narrow	Not Affected	Fast	Smart Phone Sensors	Intrusive	80%	Lab	Worker Movements
GPS	Wide	Not Affected	Fast	GPS Receivers	Intrusive	High	Outdoor	Excavation
Audio-based	One Machine	Not Affected	Fast	Microphone Array	Non	80% - 50%	Outdoor	Construction Machines
Accelerometer-based	Narrow	Not Affected	Fast	Laptop mounted with camera, Accelerometer sensor	Intrusive	80%	Lab	Masonry Work

Table 2-1. Comparison of implemented construction productivity monitoring methods (W.S. A., et al, 2022)

Chapter 3. Analysis of Modular Factory Work

Productivity

In this study, a case study methodology was used to specifically identify the main causes that hinder productivity by process. Case studies enable more in-depth analysis as a way to answer "how" and "why" questions through research (Yin, R., 1994). This study identifies why the productivity of modular factory work is lower or similar to that of traditional methods. We also analyze how work productivity inhibitors can be improved. The analysis of worker productivity in a modular factory is conducted in the following manner. Based on existing literature and expert advice, the unit production activity of the modular factory is analyzed. Based on this, through the advice of experts currently undergoing modular construction work, what causes of idle occurrence in the analyzed activities are derived, coded, and classified. Prior to the development of the measurement sheet, the classified idle causes are classified according to Lean theory and prepared for waste identification. Based on the derived lean theory-based idle cause and modular unit production activity, we develop a primary monitoring check sheet for identifying idle time and idle cause of workers and waste to be eliminated. In addition, seven modular construction experts will be selected first for monitoring construction and monitoring will be conducted in the order of the relevant construction. Based on the developed primary check sheet, the production of the modular unit mock-up that produces

three modular units is monitored, and the results based on this are revised to modify the check sheet that was developed first. Through this, worker productivity monitoring is conducted from the time of main production of the modular unit based on the modified measurement sheet. A total of two researchers are monitoring, and cross-validation is performed based on the collected data, and if different data or missing data exist, only normally verified data is collected by filtering them. Measurements were recorded in 1-minute units to solve the data discontinuity of FMR(Five-Minute Rating Method), an existing measurement method. The idle cause of the modular factory unit manufacturing workers collected in this way is defined as waste, which must be removed to improve productivity through quadrant analysis. Finally, quantitative figures of classified waste are analyzed, suggesting improvement measures for factory managers to manage them, and major management activities and improvement measures for improving modular factory worker work productivity.

Modular Factory Work Productivity Monitoring Process

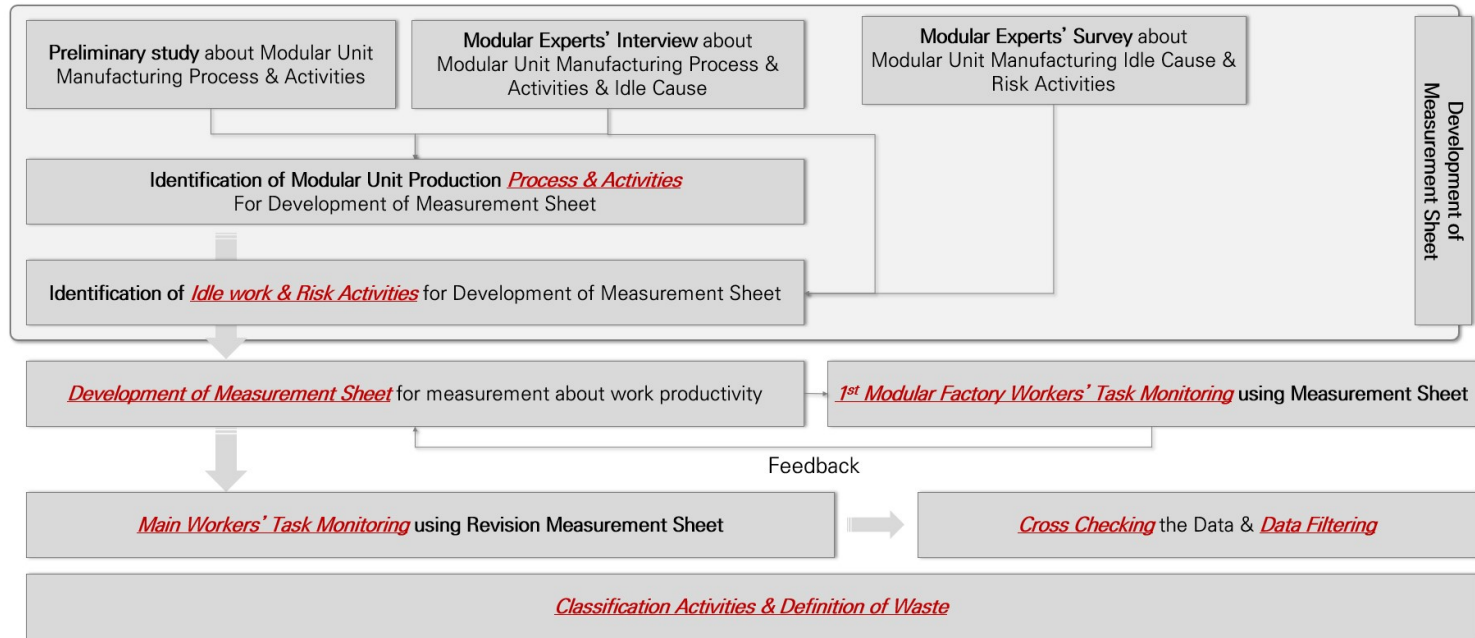


Fig 3-1. Modular Factory Work Productivity Monitoring Methodology Framework

3.1 Identification of Modular Unit Manufacturing

Activities

According to the literature related to modular factory production, few studies have classified and recorded the modular factory production process in detail up to detailed activity. Therefore, this study investigates the factory production process of modular units through a literature review (Fig 4.). In addition, interviews with five experts in the modular construction factory currently carrying out the modular project are conducted to derive the production process of the modular factory (Table 1). Based on the derived activities for each production process, pre-work is carried out to develop a productivity measurement sheet for monitoring (Fig 5.). By reflecting the activity derived from the literature review and the activity derived through expert interviews, the classification of the target industries to be monitored through the productivity measurement check sheet is clarified and the measurement is prepared. 12 major mid-to-high rise modular unit manufacturing activities were derived through literature reviews and expert interviews. Table 2 shows the key activities of the derived mid-to-high rise modular unit manufacturing.

Literature-based Modular Unit Manufacturing Process in Factory

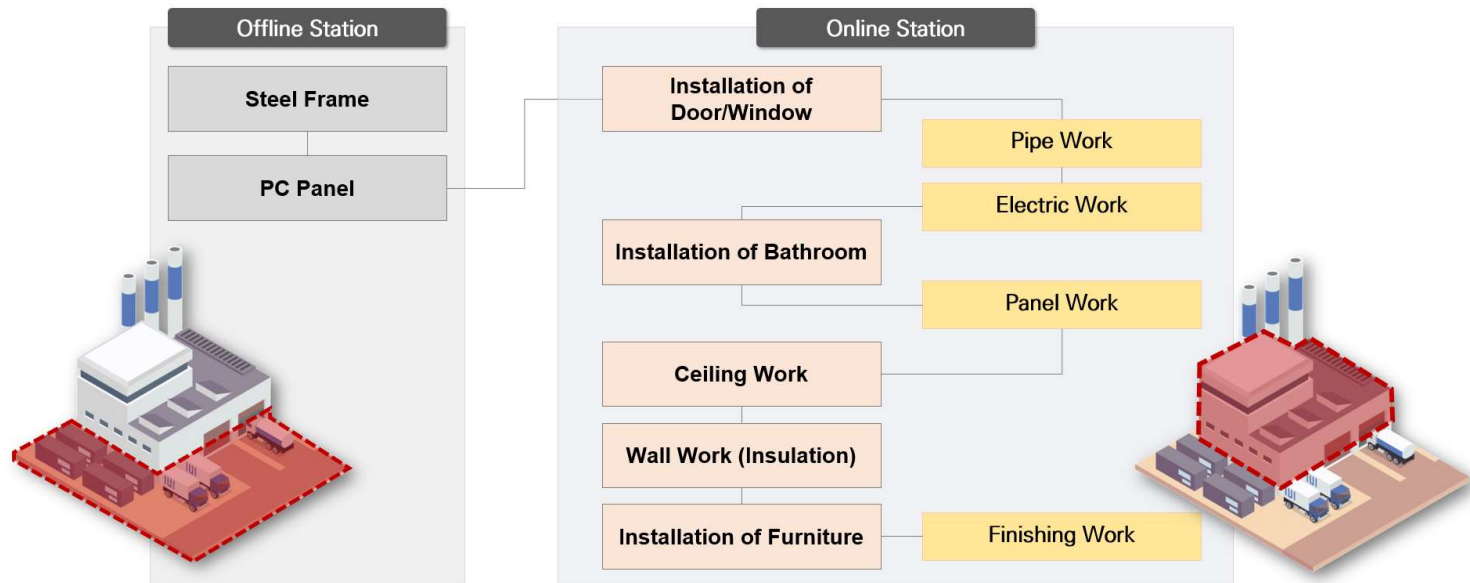


Fig 3-2. Literature : Modular Factory Manufacturing Process (Hyun, H. et al., 2021; K Rashid et al., 2020)

Expert Interview-based Modular Unit Manufacturing Process in Factory

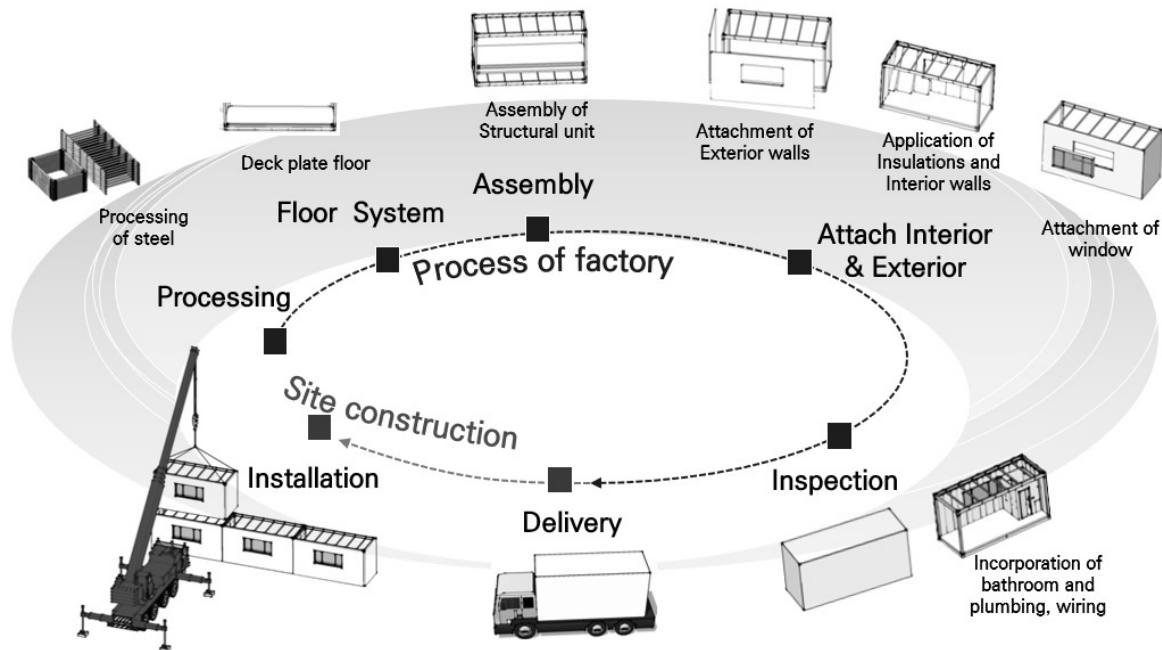


Fig 3-3. Expert Interview : Modular Factory Manufacturing Process (KumKang Co., 2022)

Expert Interview Information

Date	2021. 10. 20.
The number of Participants	5 people
Company	Hyundai Engineering Co., LTD., Kumkang Kind. Co.
Group Interview Time	about 3 hours
Age	40 ~ 60
Construction Field Experience	over 10 years
Modular Factory Experience	over 5 years (2 people)
Modular Construction Field Experience	1years ~ 5years over (3people)

Table 3-1. Expert Interview's Participants Information

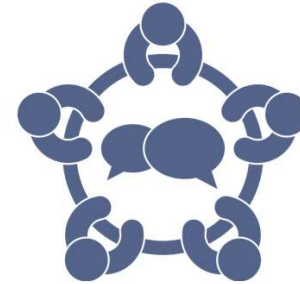


Fig 3-4. Hyundai Engineering Co.
LTD. Expert Interview

Identified Modular Unit Manufacturing Key Activities

Mid-to-High rise Modular Unit Manufacturing Key Activities

No.	Activities
1	Steel Frame Assembly Work
2	Floor Slab Pouring and Curing Work
3	Interior Finishing Work
4	Unit Bathroom Work
5	Metal, Window, Glass Work
6	Plastering Work
7	Tile Work
8	Finishing Work
9	Painting Work
10	Electrical, Telecommunication, Fire Resistance Work
11	Mechanical Work
12	Cleaning and additional Work

Table 3-2. Key Activities were derived through literature reviews and expert interviews

3.2. Development of Work Productivity

Measurement Sheet

Based on the major activities of modular unit manufacturing, the activity classification for monitoring the work productivity of factory workers was completed. Based on this, a measurement sheet is developed, and monitoring is performed (Fig 7). In addition, a step for identifying the cause of idle activity and idle time of factory unit manufacturing workers is carried out. In order to identify idle activities for the development of measurement sheets, the cause of idle activities and the preferred monitoring target industries were selected through existing literature reviews and expert surveys. In order to derive the management priority for each type of engineering, the following five measurement indicators were defined and a survey was conducted using the 5-likert scale scoring method. Among the five metrics, the highest score was first selected as the monitored activity, and the measurement sheet was developed by deriving idle causes that may occur during the modular unit production process through the existing literature review.

The modular unit production process is defined as shown in Figure 7, and although there are differences in detailed activities depending on (1) production method and (2) factory production level of the modular unit, general modular unit production activities are defined as shown in Table 3. In this survey, management-first activities according to each activity were derived, and the defined indicators were used to derive the expected cause of work idle. Five

Identified Modular Unit Manufacturing Key Activities

Mid-to-High Rise Modular Unit Manufacturing Key Activities	
No.	Activities
01	Steel Frame work construction
02	Floor Slab Pouring and Curing
03	Interior Finishing Work
04	Unit Bath room Work
05	Metal, Window, Glass Work
06	Plastering Work
07	Tile Work
08	Finishing Work
09	Painting Work
10	Electrical, Telecommunication, Fire Resistant Work
11	Mechanical Work
12	Cleaning and additional Work

<

Fig 3-5. Identification of Modular Unit Manufacturing Activities for Measurement about Work Productivity

measurement indicators were defined, and a survey was conducted through a scoring method on a 5-likert scale. The higher the score assigned, the higher the main activity, or the higher the management priority.

Duration

In the case of activity with long air, it is greatly influenced by worker proficiency in the process of performance or the occurrence of variables is high. For each activity, scores were given by sorting the time it took to perform the activity in ascending order as the standard working period. One point was given as Activity with the shortest working period, and five points were given as Activity with the longest working period.

Activity Relation

A common species with high dependence on the prior activity and complexity of the prior and subsequent relationships was defined as having a high management priority. It refers to the complexity of the preceding and following processes, and the score of the activity is given according to the following evaluation criteria.

- 1 point: Activity without prior activity
- 2 point: There is a prior activity, but it can be performed simultaneously in parallel depending on the situation
- 3 point: Activities that must be carried out in advance
- 4 point: Activities that are highly influenced by subsequent activities as

major activities

- 5 point: The relationship between the preceding and the following is complicated, and the activity is performed several times in stages rather than in a single activity

Risk Factor

There is a difference between the degree of risk occurrence and the risk management method according to activities. Activity with a high level of risk occurrence due to workers or external factors was defined as having many factors that hinder productivity. Activity with a high risk of unspecified variables due to the level of risk for each activity and external factors is defined as the highest risk activity.

- 1 point: Activity that does not cause delays in working hours due to external factors
- 2 point: Activity with a very small risk of delay in working hours due to external factors
- 3 point: Activity that can shorten or delay the work time according to the skill level of the worker
- 4 point: Activity that is feared to delay working hours due to the influence of external factors
- 5 point: Activity where the average working time is different due to the high risk

Crowdness

It means the level of work congestion within the modular unit. It was defined that when the number of workers simultaneously put into one modular unit increases, complexity increases and acts as a cause of productivity inhibition. It defines activity with a large number of workers simultaneously put into the work as having high complexity.

- 1 point: Activity performed by only 1 worker
- 2 point: Activity that can be performed by one worker (performed with additional personnel depending on the situation)
- 3 point: Activities that can reduce working hours by employing two workers
- 4 point: Activity generally performed by putting two workers
- 5 point: Activities that require two or more workers

Lead Time

If a lead time occurs in relation to materials, a delay in the construction period or a decrease in productivity occurs. It was defined that the management priority was high when the impact was high, such as the supply and demand of materials or modules manufactured in advance. In order to evaluate the degree of material-related lead time, scores were assigned according to the following definition.

- 1 point: Activity not affected by material procurement

- 2 point: Activity without significant difficulty in procuring materials
- 3 point: Activity that may cause delays in construction period due to material procurement
- 4 point: Activity that requires a lot of required materials and requires pre- and custom-made production, which can lead time
- 5 point: Activity in which a separate contract is carried out because pre-built modules(e.g. UBR) and materials are required

Activities to be Monitored Intensively

Survey about Activities to be Monitored Intensively

	Duration	Activity Relation	Risk Factor	Crowdness	Lead Time	Average	Rank
Door / Window Work	1.7	2.3	2.0	4.0	3.3	2.7	7
Pipe Work	2.3	3.0	2.7	4.3	2.7	3.0	6
Electric Work	2.3	3.0	4.0	4.0	2.3	3.1	5
Bathroom Work	3.0	3.7	3.7	4.3	2.3	3.4	4
Panel Work	4.0	3.0	3.3	5.0	3.3	3.7	2
Ceiling Work	4.3	4.0	3.3	5.0	2.3	3.8	1
Wall Work	3.7	3.3	3.0	4.7	3.3	3.6	3
Furniture Work	1.7	4.0	1.0	3.7	2.7	2.6	8
Finishing Work	4.3	4.3	3.0	4.7	2.3	3.8	1

Table 3-3. Expert Survey Results about Activities to be Monitored Intensively

3.3. Measurement of Modular Unit Manufacturing Work Productivity

In addition to reviews of existing literature, we classify the expected idle tasks by reflecting the key activities to be proactively managed and influential indicators that may cause defined productivity impediments. There are four main categories, and idle causes are classified.

- (1) Worker idle activities that may normally occur in the preparation or movement of work
- (2) Worker idle activities that may only occur in the production of modular units, such as lack of space in the field, etc
- (3) Worker idle activities related to materials and equipment
- (4) It was classified as an idle activity of workers related to safety and modular unit quality.

Detailed idle activities for each category are shown in Table 4.

Activities to be Monitored Intensively

Class.	Idle Work	Code	Class.	Idle Work	Code	Class.	Idle Work	Code
Common Issue	Work Preparation	C01	Modular Specific	Mdoular Unit Import & Export	M01	Safety & Quality	Not Following Safety Instruction	S01
	Other Work miscommunication	C02		Narrow space due to Factory Unit Layout	M02		Safety Accident	S02
	Other Work Interference	C03		Lack of Unit Yard Space	M03		Safety Training	S03
	Other Work Supporting	C04		Modular Unit Transport Vehicles Delay	M04		Quality Assurance Training	S04
	Rework(Re-Manufacturing)	C05		Lack of Modular Experience	M05		Mdoular Unit Quality Error	S05
	Change of Work Plan	C06		Production Rate down on purpose	M06		Specification Error Correction	S06
	Predecessor Activity Delay	C07	Material & Equipment	Equipment Setting	E01		Inspection Wait	S07
	Cleaning	C08		Equipment Failure	E02		Contractor Request	S08
	Extreme Temperature (Heat)	C09		Equipment Shortage	E03		Supervision Inspection	S09
	Early Departure from work	C10		Material Shortage	E04		Paper Work Delay	S10
	Travel (Non-work)	C11		Material Delivery Delay	E05			
	Travel (Work)	C12		Material Unloading Delay	E06			
	Rest / Toilet Use / Smoking	C13		Material Filure	E07			

Table 3-4. Cause of Modular Production Idle Work (based on Literature & Mok-up Monitoring)

3.4. Definition of Waste in Modular Unit Manufacturing Based on Lean Theory

It is necessary to realize "just-in-time" of the production line as a way to improve productivity in the current modular unit production factory, which is less productive. "Just-in-time" first appeared in Toyota Motor Corporation's concept of lean production and means successfully completing the work within the time allocated to the production line without any waste. Modular production lines have the characteristics of the construction industry at the same time. In particular, in the static production line, work is carried out centered on people. Accordingly, there is a problem in that the cause of idle of the worker is diversified. Therefore, it is difficult to apply the Lean Theory, which was applied in the existing manufacturing industry. In order to minimize waste in the production line by applying Lean theory to the modular production line, it is necessary to define waste suitable for the modular characteristics. Therefore, it is necessary to classify activities that create value in actual production and activities that hinder value. In particular, it is necessary to define unnecessary activities among activities that hinder value as waste. Activities defined as waste can also be seen as a major management factor to improve work productivity of factories.

Classification of Idle Activities based on Lean Theory

The eight elements of waste defined by Lean Theory are shown in Table 6.

Class.	No.	Waste Types	Description
Labor	1	Waiting	The waste of waiting occurs when work-in-progress or people are waiting on the next step in production.Waiting is an extremely common type of waste that can occur in many different ways across design and construction projects.
	2	Motion	Unnecessary or excessive motion can be described as unnecessary movement by people or movement that does not add value.unnecessary motion often occurs on job sites when workers are constantly shuttling back and forth across the room to grab materials situated away from their work station.
	3	Extra-processing	Over processing is the act of taking unnecessary steps in a process.Naturally, under processing would be neglecting to take necessary steps in a process. This was one of the most prominent types of waste, slimming down the manufacturing process to include only the necessary steps – or the steps that directly produced value.
	4	Transportation	Unnecessary transportation waste includes creating inefficient transport, moving raw materials, parts, equipment, or information into or out of storage or between processes.Unnecessary transportation occurs when pull planning is poor or when there isn't a plan for the storage of materials for safekeeping until they are needed.
Materials	5	Inventory	Excess inventory waste occurs when product, materials, work-in-progress or information quantities go beyond supporting the immediate need. Anything that is a buffer could be explored as waste.
	6	Over production	Over and under production can be defined as making something before it is truly needed.In other words: not producing the right work at the right time in the right amount as needed by the downstream work.
Service	7	Defects	Defects occur when there is a production of defective parts, work or information that causes the work to be scrapped or redone. This leads to rework, one of the biggest causes of waste and a practice that commonly leads to projects being delivered late and over-budget.
Human Potential	8	Talent	Wastes due to underutilization of people's talents, skills, and knowledge.

Table 3-5. Toyota Lean Production Systems “8 Wastes”
(Florentino Rico et al., 2014)

The cause of the idle work derived earlier was filtered through worker monitoring. A total of 21 idle causes were derived for the modular factory unit production work. In order to define waste, the idle causes derived were reclassified according to the eight wastes defined in Lean Theory. The causes of the re-classified idle are shown in Table 7.

Based on Table 7, among the activities classified as idle activities, activities that affect productivity if the activity is not managed from a comprehensive perspective and those that are helpful in values other than productivity are classified as value added activities. In addition to classified value-generating activities, idle activities that substantially unnecessarily delay or interrupt work have been classified as activities that hinder value. And these activities are defined as non-value added activity. It is clear that activities that undermine value should be avoided. However, among the activities that hinder value, there are activities that must be included in production activities. For example, in the case of rest, if it is an activity in which a person works, the efficiency of work may increase further when some time of rest exists. Therefore, all of the classified non-value added activities are classified as waste and not set as management targets, but are divided into essential and unnecessary activities and defined as waste.

Using quadrant analysis, each idle activity is classified into an activity that creates value and an activity that undermines value, and again, it is classified into essential and unnecessary activities, and finally, unnecessary activities are defined as waste. This is shown in Figure 8. Activities defined as waste are

identified as idle tasks that need to be managed intensively to improve productivity during the production of modular units.

No.	Class.	Cause of Idle Work
1	2	Move (Non-work, over 1.5m move)
2	1	Counting the number of workers
3	1	Safety Education
4	1	Preparation of Materials
5	2,3,4	Deliver Materials
6	1,7,8	Work Instructions
7	1,2	Rest (Smoking, Physiological Phenomenon etc.)
8	1,3,7	Preceding Work Delay
9	1,2,3	Communication
10	1,2,3,8	Work interference
11	1,6,7,8	Supervisor's Inspection
12	2,6	Early Departure
13	2,6	Return to Work Late
14	2,4,3	Deliver Equipment
15	1,6,7	Re-work
16	1	Wait for Work
17	7	Equipment Inspection
18	7	Equipment Defect
19	2,3	Support other Works
20	1,3,8	Preparation of Work
21	2	Site Clean-up

Table 3-6. Classification of Idle Causes based on Lean Theory

Quadrant Analysis for Definition of Waste in Modular Factory Work

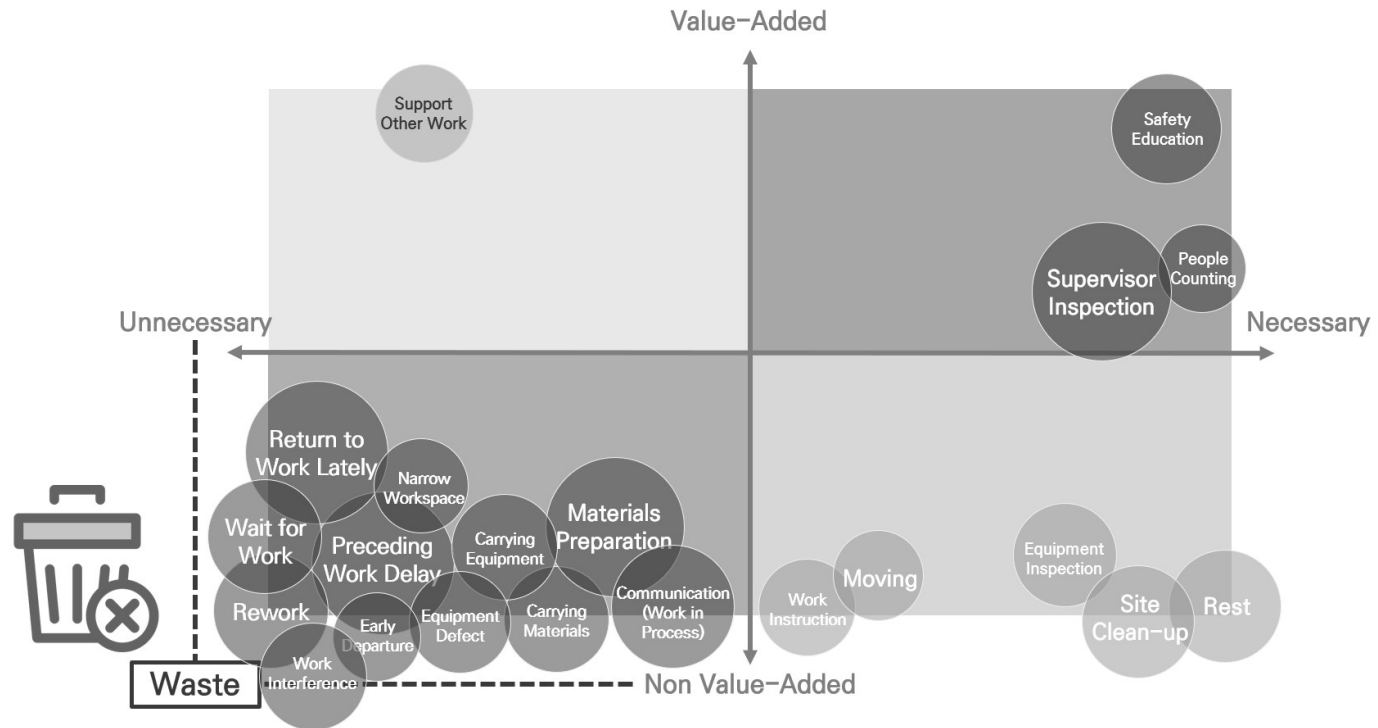


Fig 3-6. Classification Value Added Activity and Non-Value Added Activity & Definition of Waste

Chapter 4. Case Study

Based on this, the development of the primary work productivity monitoring measurement sheet is completed, and before main monitoring using the developed measurement sheet, the modular unit mok-up production is monitored first to modify the developed measurement sheet. The modified measurement sheet based on the modular unit mok-up production monitoring was used to monitor the productivity of the main modular unit production. Information on projects and factories that have been monitored for work productivity is presented in Table 9 and Figures 11. Monitoring was conducted by directly observing workers in the factory from two researchers. Two researchers monitored the corresponding same activity at the same time. Two researchers cross-checked the data collected in this way, filtered the data of the same measured part, and collected it as work productivity data. Measurements were made during the period '22-09-19' to '22-11-04, and a total of 26 activity monitoring were performed. The measurement was made in units of one modular unit. A stopwatch was used as a tool for measurement, and the worker's work status was determined every minute, and real and non-work were classified and recorded. In addition, according to the lean theory, movement of more than 1.5m is defined as waste, so the range of actual workers working is set to a radius of 1.5m based on the module they are working on. A sample of the measured data is shown in Fig 12.

Monitoring Project Description

Mid-to-High Rise Modular Construction Project Description	
Category	Description
Project Name	YounginYeongdeokGyeonggi Public Housing
Business Owner	GH(Gyeonggi Housing and Urban Corporation)
Location	550-1 Yeongdeok-dong, Giheung-gu, Yongin-si, Gyeonggi-do, Republic of Korea
Building Type	Apartment house (106 household)
Height	13 story (49.91m)
Gross Floor Area	6,967.94m ²
Floor Area Ratio	166.33%
Project Duration	‘22. 01. 01 ~ ‘23. 06. 30.
Number of Modular Unit	110 modular units
Number of Households	106 (17m ² : 102 / 37m ² : 4)

Table 4-1. Monitoring Project Description

Monitoring Modular Factory Description

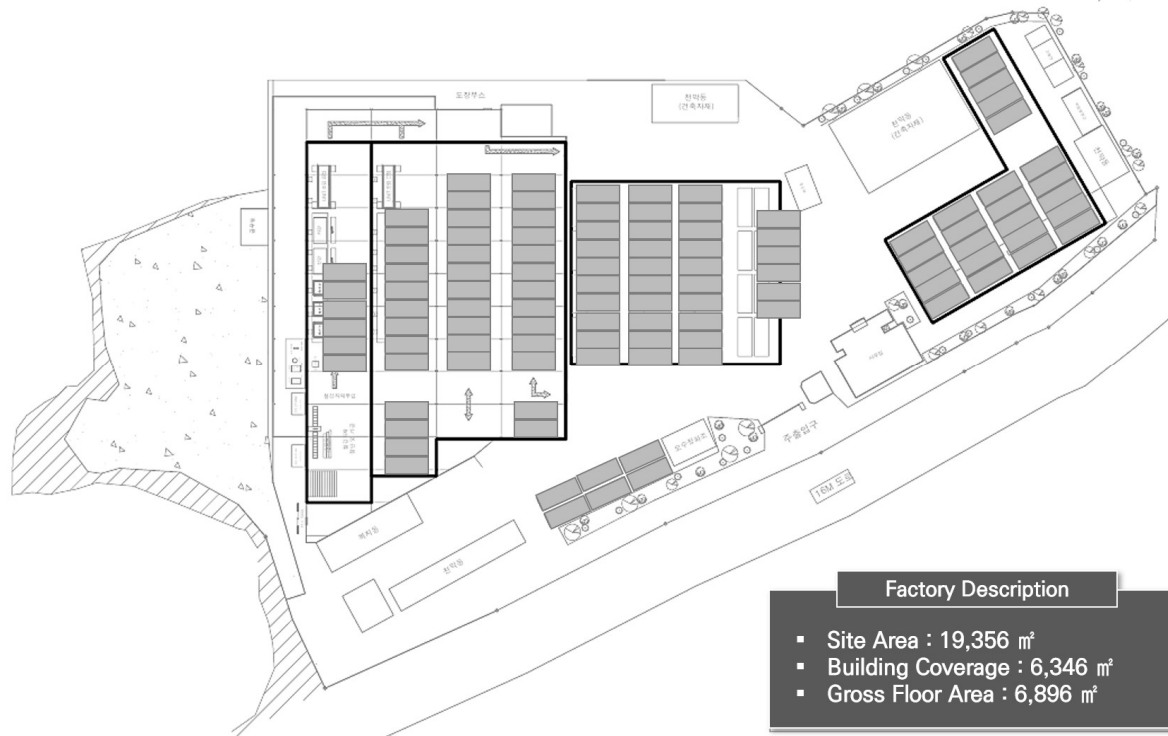


Figure 4-1. Modular Factory Description (capacity : 3,000units/year)

Modular Unit Production Layout Description

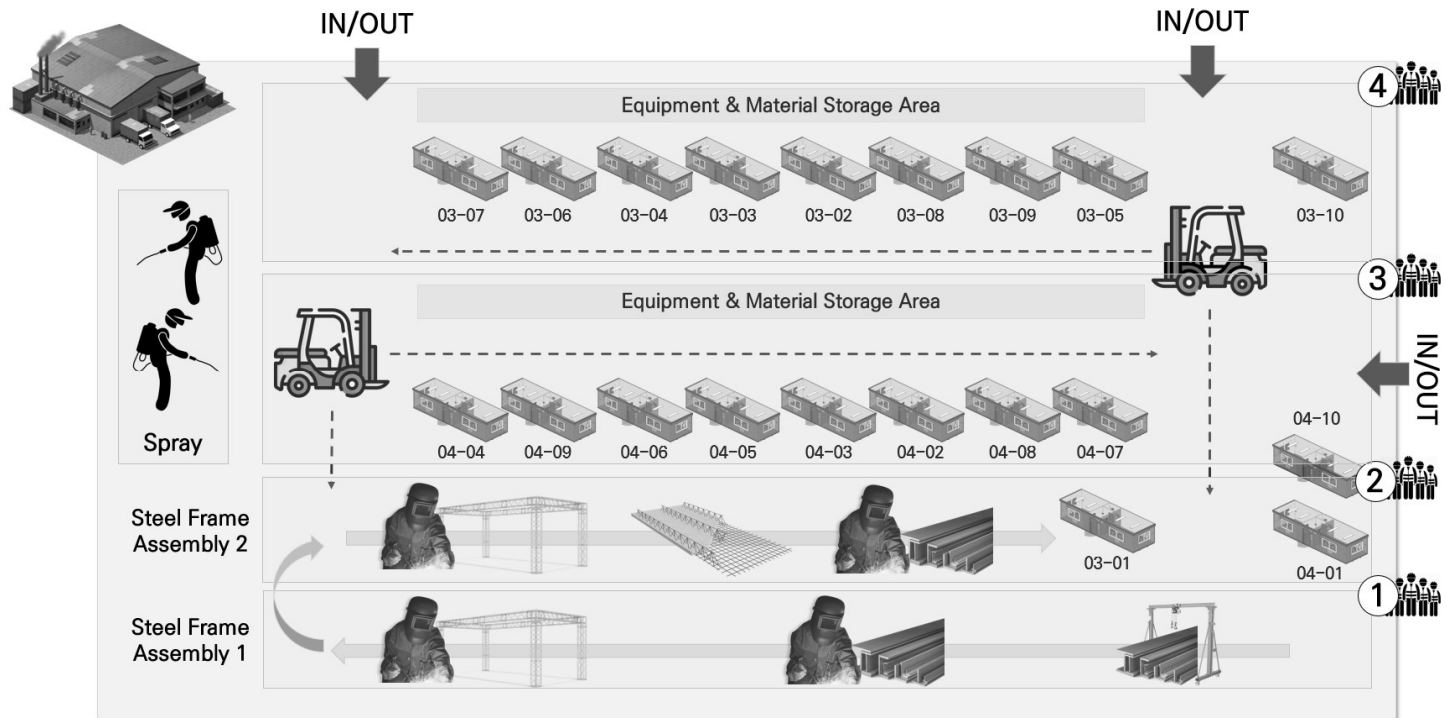


Figure 4-2. Modular Unit Production Layout in the Factory

Monitoring was carried out by the following process. One researcher records the entire work period from the start to the end of the work day, and one other researcher records the work of the same worker at the same time. Each activity was sequentially monitored according to the modular process sequence shown in Table 9. One researcher observed about 1 to 3 workers according to each activity. In addition, from the time when each activity began to end, two researchers measured the cause of work and idle in each division. Each activity was monitored based on one modular unit, and the time of each activity operation and idle cause was measured for a total of three modular units. If the worker deviates from the unit radius of 1.5m, this is considered as a non-work possibility, and the causes of the worker's departure from the work area were recorded in detail. Work productivity monitoring was conducted for approximately two months, and measurements of all activity for work in the factory were conducted, which is the core of modular construction productivity. A total of 34 modular factory manufacturing activities were identified, as shown in Table 9 and Figure 11. In practice, task monitoring was conducted on 17 activities. For conversations or breaks of less than a minute, this is a simple matter that may occur during work and is not reflected as a cause of worker idle. As a result, the measurement of the work productivity of factory workers in units of one minute was carried out.

Detailed Activity by Monitoring

No.	Detailed Activity	Station
1	Raw Material Deliver to Factory	Steel Structure Frame Assembly Station
2	Welding of Steel Material	
3	Material Carrying by Over-head crane	
4	Welding of Steel Structure	
5	Placement of Slab Rebar	
6	Binding of Slab Rebar	
7	Carrying Modular Unit to Spray Zone	
8	Spray on Steel Structure	
9	Carrying Modular Unit on Anchor	Modular Unit Manufacturing Station in the Factory
10	Pouring Slab Concrete	
11	Concrete Curing	
12	Welding Light Weight Steel on Structure	
13	Installation of Fire Resistance Gypsum Board	
14	Installation of Light Weight Steel Stud & Runner	
15	Installation of Door & Window Frame	
16	Installation of 1 st Gypsum Board	
17	Vinyl Waterproof Work	
18	Installation of 2 nd Gypsum Board	
19	Installation of Insulation	
20	Installation of External Plywood	
21	Installation of External Insulation & Packing	
22	Carrying Modular Unit to Outside Yard	
23	Ceiling Finishing Work	Modular Unit Manufacturing in Outside Yard
24	Installation of Bathroom	
25	Installation of Floor Insulation	
26	1 st Lightweight Bubble Concrete	
27	Installation of Floor Heating Plumbing	
28	2 nd Lightweight Bubble Concrete	
29	Installation of Inner Ceiling Gypsum Board	
30	Other Finishing Work	
31	Installation of Furniture	
32	Exterior Finishing Work	
33	Modular Unit Quality Inspection	
34	Deliver to Construction Site	

Table 4-2. Detailed Activities by Work Productivity Monitoring

Mid-to-High Rise Modular Unit Manufacturing Process



Fig. Steel Material Welding



Fig. Material Carrying by Over Head Crane



Fig. Steel Structure Welding



Fig. Slab Rebar Placement



Fig. Slab Rebar Binding



Fig. Carrying Modular Unit Using Forklift



Fig. Spray on Steel Structure



Fig. Carrying Modular Unit on the Anchor



Fig. Pouring Slab Concrete



Fig. Concrete Curing



Fig. Concrete Curing (2 days after)



Fig. Welding Light Weight Steel on Structure



Fig. Installation of Fire Resistance gypsum



Fig. Installation of Fire Resistance Gypsum



Fig. Installation of Windows & Doors Frame



Fig. Installation of 1st Gypsum Board



Fig. Vinyl Waterproof install



Fig. Installation of 2nd Gypsum Board



Fig. Insulation Installation

20



Fig. External Plywood Installation

21



Fig. External Insulation Install & Packing

22



Fig. Carrying Modular Unit to Outside

23

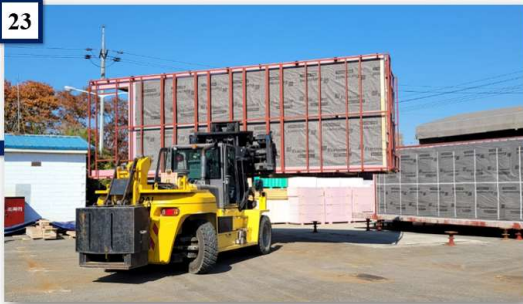


Fig. Carrying Modular Unit to Outside

24

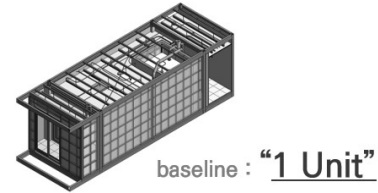


Fig. Ceiling Finishing

The measurement sheet for the measurement is given the date of the monitoring, the activity being performed, the information of the unit, and the worker ID to display information about the basic monitoring. The measurement information content records the start and end of each worker's work or idle activity. In the case of idle activities, the work status was classified as 0, and the actual work performance was indicated as 1. In addition, idle activities were recorded through codes assigned for each idle activity. The full information displays the total time that the activity was performed relative to one unit. The overall Value Added Time displays the time of activity that the actual worker being measured creates the value of the job in performing the activity. In addition, Non Value Added Time represents the total amount of time that the person monitoring is taking to perform the activity that impairs the value of the work. Finally, waste time refers to the total time corresponding to waste as defined in Figure 8. Idle information is based on the code assigned for each Idle activity, indicating a more detailed Idle Time for that code and showing it as a percentage at the same time. The form of the overall measurement sheet configuration is shown in Figure 12.

Modular Factory Work Productivity Measurement Sheet

Work Productivity Monitoring Check Sheet					
Date	2022-09-19				
Activity	Installation of Light Weight Steel Stud & Runner				
Unit Number	YY-3-02				
Worker ID	S_worker1				
Total Information					
Cycle Time (1Unit)	380 min				
Total Value Added Time	177 min				
Total Non Value Added Time	203 min				
Total Waste Time	104 min				
Measurement Information					
Start Time	End Time	Status	Issue	Comment	
08:00	08:02	0	S01		
08:02	08:05	0	S02		
08:05	08:07	0	S03		
08:07	08:09	0	S01		
		⋮		Unit 3-02 Finish	
16:25	16:30	0	C3		
16:30	18:00	1	Work		
IDLE Information					
Total IDLE Time	281	46.83(%)			
C1	6	2.71(%)	M01	8	3.26(%)
C2	0	0.00(%)	M02	0	0.00(%)
C3	49	22.17(%)	M03	0	0.00(%)
C4	32	14.48(%)	M04	0	0.00(%)
	⋮				



$$Cycle\ Time = \sum Value\ Added\ Time + Non\ Value\ Added\ Time$$

$$Value\ Added\ Time = \sum Actual\ Work\ Time$$

$$Non\ Value\ Added\ Time = \sum Idle\ Work\ Time$$

$$Waste\ Time = \sum Time\ Defined\ as\ Waste$$

Fig 4-7. Final Work Productivity Measurement Sheet

As a result of the measurement, the total time it took to manufacture one unit was measured as 1 day 8 hours 52 minutes. The longest and most wasteful task is the Installation of Fire Resistance Gypsum Board task. The Installation of Fire Resistance Gypsum Board Activity accounts for about 27.93% of the production time of one unit, and the waste time is 217 minutes, resulting in a total of 39.38% of waste in producing one unit.

Second, the waste-prone task is Installation of Light Weight Steel Stud & Runner Activity. It accounts for about 20.55% of the total time taken to manufacture one unit, and the waste time of the work was measured to be 150 minutes. This is causing a total of 37.12% of waste in the task.

The third most wasteful activity is the Installation of indoor sealing Gypsum Board Activity. It accounts for about 23.52% of the total time it takes to manufacture one unit. Waste time was measured 101 minutes. It can be seen that a total of 21.77% of waste is occurring in the work. The actual total working time to produce one unit as a whole was measured at 1 day 8 hours 52 minutes, and it was found that the working time was 1 day 2 hours 58 minutes(Fig 13) if only Value Added Activity was actually performed except for waste. If waste is removed, the working time corresponding to about 6 hours per unit can be reduced. Table 10 shows detailed measurement results for the top three activities with the most waste.

Activity	Total Cycle Time (minute)	Total Value Added Time (minute)	(%)	Waste Time (minute)	(%)	Rank
Installation of Fire Resistance Gypsum Board	551	334	60.62	217	39.38	1
Installation of Light Weight Steel Stud & Runner	405.5	255	62.88	150	37.12	2
Installation of 1 st Gypsum Board	455.5	205.5	45.12	250	54.88	4
Vinyl Water proof Work	296.5	176.25	59.44	120.25	40.56	5
Installation of 2 nd Gypsum Board	214	123.5	57.71	90.5	42.29	6
Installation of Insulation	149.3	110.3	73.88	39	26.12	7
Installation of External Plywood	51	30	58.82	21	41.18	8
Installation of Indoor ceiling Gypsum Board	464	363	78.23	101	21.77	3

Table 4-3. The most low Waste Time 8 Activities per 1 Unit

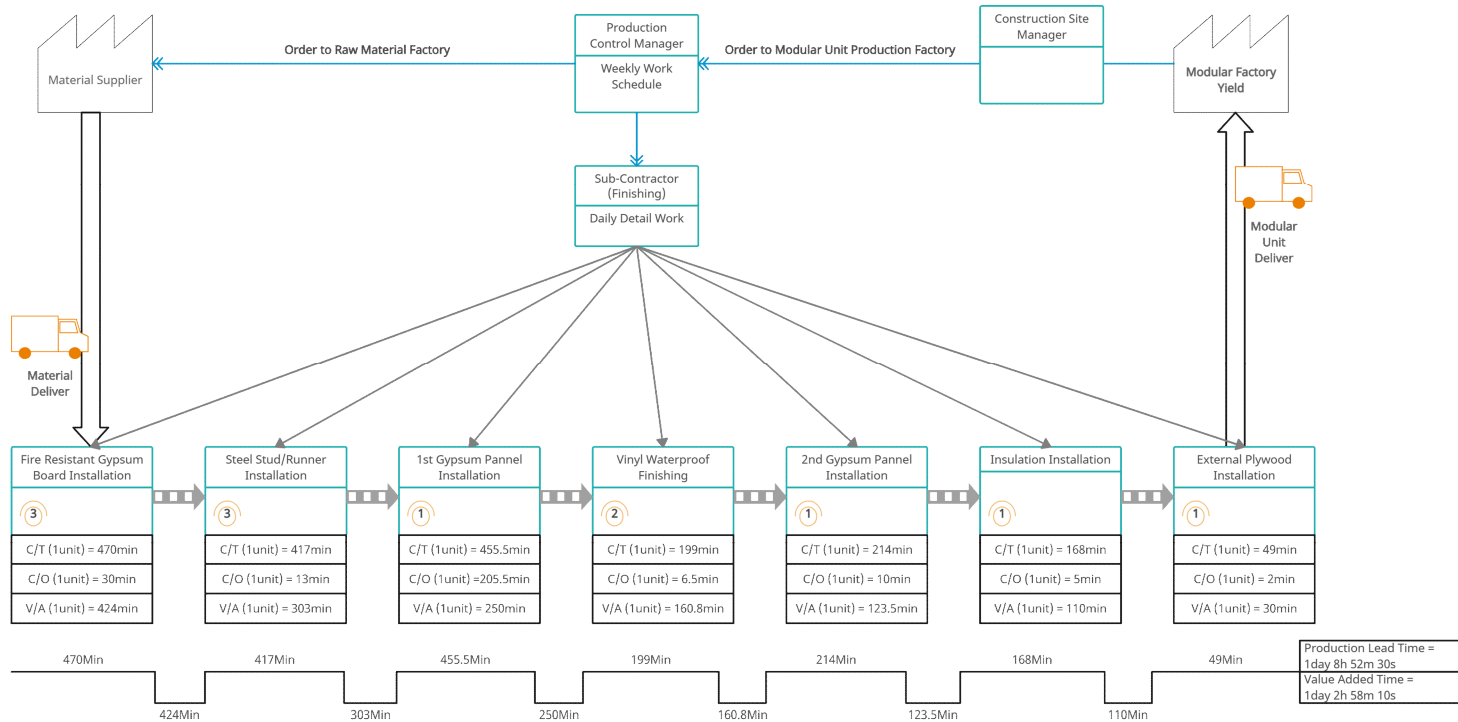


Fig 4-8. Current Value Stream Map in Mid-to-High Rise Modular Unit Manufacturing

Chapter 5. Discussion

5.1. Discussion

Several major improvement strategy could be considered by analyzing the activity where waste occurs a lot and the main cause of waste. Looking at the results of the case study, it can be seen that there is a lot of waste in the processing of materials. In particular, the part related to these materials is considered to be a problem that can be sufficiently solved as long as the plan at the initial stage of design is well established. In addition, although the modular factory manufacturing work has a different environment from the traditional construction method, it was confirmed that the workers who are familiar with the existing traditional construction method are mainly employed. Therefore, there were inexperienced parts in the fabrication of modular factory units, and it was confirmed that the work speed of the workers was leveled from the time of completion of about three units. If it is possible to eliminate the waste at the initial point due to such unskilledness, it is thought that this can also contribute to productivity improvement. Another factor that affects the occurrence of waste due to unskilledness is the communication problem between frequent workers or engineers caused by unskilledness. Frequent communication leads to a wait for work, which also leads to a lot of waste. Therefore, this research also propose the main factors that can improve this waste.

Table 12 shows the percentage of waste identified in the modular unit production process, (1) Guide for Work 22.17% (2) Work Preparation 15.65% (3) Late Arrival 15.38% (4) Communication 10.86% in order, indicating that unit production is delayed by the major factors.

In the case of work instructions, which account for the highest percentage, it occurs frequently between workers and managers. Since orders for modular projects are extremely rare, very few workers have experience in making units for modular projects. Therefore, in most cases, workers who were mainly working at existing construction sites join the modular project and proceed with the work. In addition, even workers who have experience in making units in modular projects have difficulty applying the existing experience as it is because the design of the units is all different for each modular project. Therefore, the workers who make the modular unit are not very skilled in the work, and the manager intervenes in the middle of the work to give instructions on what to pay attention to when working to ensure the unit quality and prevent delays in advance. In particular, this situation frequently occurs between managers and workers in the early stages of unit production. In order to solve this phenomenon, the increase in the amount of orders for modular projects must be preceded. In addition, standardization of unit design will increase the proficiency of modular workers and adaptability to the new environment, and this delay in work will be eliminated.

The second highest percentage factor is work preparation. Job preparation refers to the overall preparation work for the actual work before the work is

started and while performing the work. In particular, it was measured focusing on the act of checking the dimensions of the unit and preparing and processing materials by reflecting them to performing actual work. In the modular unit manufacturing process, a large amount of gypsum boards are used to meet the fire resistance standards, and it was confirmed that a large delay occurs when preparing a work because of processing them one by one. Looking at the production lines of other industries, especially automobile factories, workers will simply assemble and install standardized materials within the assigned work line without processing any materials. In order to promote ideal factory production, modular factory production lines also need to minimize waste on work preparation. If the standardization of materials allows workers in the factory to minimize work preparation time, a very simple iteration of the actual work will increase, which can lead to a rapid increase in the skill of the worker. In addition, it is thought that the biggest productivity improvement can be expected because delay can be greatly shortened.

The third highest measured factor is the late arrival. Since this study selected a middle and high-rise modular project as a case study and monitored for one project, the management of the late arrival may vary from project to project. It is thought that each manager can show a different performance. However, the reason for such a high measurement may be that workers have not experienced many of these environments due to work performed in a different environment such as factory production.

The fourth highest measured factor is the delay due to communication. This

is also associated with the work instruction, which was measured the highest. Communication between team members or other workers occurs frequently due to the nature of the Static Production Line, which moves around fixed units as a team, even if the manager instructs them to work. In addition, if the work instructions that managers deliver to the leaders of each team are not clearly delivered, this causes communication problems between workers and leads to work delays. Although the modular construction method brought about the manufacturing industry's factory production method, this communication problem occurs more frequently because workers working at traditional construction sites work on modular projects. This communication problem occurs significantly until the learning effect through repetitive tasks appears. Managers need to participate in the production of modular units that are new to workers from the early stages of design and share their work contents. Through this, it is necessary to quickly increase the speed of adaptation to the new environment when working. In addition, since it is a method of ordering from the site to the unit production factory, it is also important to respond quickly to changes in advance through active communication between factory and site officials. However, these communication problems are thought to be sufficiently likely to solve communication problems as orders for modular projects increase, unit design becomes standardized, and materials for unit production become standardized.

Based on this, the following suggestions are made to improve the productivity of modular factories.

Standardization of Materials

Based on Table 11, the most important element of waste is work preparation and work instruction. The reason for this is that in the case of installing a gypsum board or installing a lightweight steel member, the material is cut and installed inside the unit according to the size of the unit. This is similar to the lightweight steel work installed on the lightweight steel member. The waste is very severe because the narrow space for cutting materials and each unit is directly measured and cut for each unit. In order to solve this problem, it is necessary to standardize materials suitable for modulators. The operator's actual transport and installation of the gypsum board is very fast. Therefore, if the material is standardized, it becomes possible to repeat the modular factory work that is ideally becomes possible. In addition, it is expected that 15.65% of work preparation time can be shortened.

Improvement of Material Performance

In the case of Installation of Fire Resistance Gypsum Board work, which is the most wasteful activity, a total of four layers of gypsum boards are installed to meet fire resistance performance. In particular, since a refractory gypsum board is installed in the structural part, more detailed cutting of the material becomes necessary. However, as a method for fire resistance, not only the method using the insulation exists, but fire resistance can be ensured through a spray with fire resistance. Since it is cheaper than insulation and has much less labor, it is necessary to think about materials that can improve performance like this. If a spray is used to improve fire resistance, the total time to

install four layers of gypsum boards is changed to spraying several times, so it is expected to improve the productivity of the factory work.

The Rate of Waste in Modular Factory Work

No.	Waste	Code Number	Rate of Waste (%)
3	Early Departure	C03	5.43
4	Late Arrival	C04	15.38
5	Guide for Work	C05	22.17
6	Predecessor Work Delay	C06	0
7	Communication	C07	10.86
8	Work Interference	C08	5.43
9	Rework	C09	2.71
10	Wait during work	C10	3.62
13	Work Preparation	C13	15.65
14	Material Preparation	M01	2.71
15	Equipment Preparation	M02	0
16	Material Carrying	M03	0
18	Equipment Failure	M05	0

Table 5-1. The Rate of Waste (Waste Time / Total Cycle Time)

Chapter 6. Conclusion

It is expected that the modular construction method can overcome the limitations of the existing traditional construction method, but the productivity of the modular construction method does not show much difference from the existing traditional construction method. Therefore, in order to promote more active application of the modular construction method, parts that can lower construction costs and improve productivity must be considered in advance. Existing studies related to the productivity of the modular method rarely exist, and research based on opinions has been mainly conducted. However, these opinion-based studies mainly used surveys or interviews to identify the main factors affecting productivity at the project level, which is a macro perspective. In order to improve productivity, it is necessary to collect and analyze the data needed for productivity, but it is not easy to collect data due to the nature of modular projects with an extremely rare number of projects. Therefore, this study conducts a case study on modular unit production plants where most of the production activities are carried out in factories. In order to collect the most accurate data as a measurement tool for productivity measurement, a method of observing the researcher directly residing in the factory was used, and data collection was conducted for about two months. A case study was conducted based on the main factors affecting productivity presented in the previous studies, and the answer to why these factors occurred at the activity level beyond the macro-level factor identification, which was a limitation of

the previous studies. Through this, the activity that generates the most waste in the current factory production was identified, and the main cause of the waste was identified through case studies. The results of this study can be used as data data that is the basis for future modular research. It can also help stakeholders in modular projects, especially those in factories and sites, make decisions. The modular construction method is currently making great efforts for high-rise and automation. The results of the data collected in this study are also significant as basic data for the high-rise and automation of modular construction.

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Appendices

Appendix A : Classification of Non-Work Factors' Code

**Appendix B : Modular Factory Labor Productivity
Monitoring Data**

Appendix A : Classification of Non-Work Factors' Code

No.	Category	Activities	Code Number
1	Common	Rest	C01
2	Common	Move	C02
3	Common	Early Departure	C03
4	Common	Late Arrival	C04
5	Common	Guide for Work	C05
6	Common	Predecessor Work Delay	C06
7	Common	Communication	C07
8	Common	Work Interference	C08
9	Common	Rework	C09
10	Common	Wait during work	C10
11	Common	Support other work	C11
12	Common	Site Clean-up	C12
13	Material & Equipment	Material Preparation	M01
14	Material & Equipment	Material Carrying	M02
15	Material & Equipment	Equipment Carrying	M03
16	Material & Equipment	Individual Equipment Setting	M04
17	Material & Equipment	Equipment Defect	M05
18	Material & Equipment	Supervisor Inspection	S01
19	Material & Equipment	People Counting	S02
20	Material & Equipment	Safety Education	S03

Appendix B : Modular Factory Workers' Task

Monitoring Data

Activity	Installation of Light Weight Steel Runner & Stud			
Date	2022-09-19			
Modular Unit	No. 302			
Worker	Light Weight Steel Installation Worker			
No.	Work Start	Work End	Status	Issue
1	08:00	08:02	0	C02
2	08:02	08:05	0	S02
3	08:05	08:07	0	S03
4	08:07	08:09	0	C02
5	08:09	08:11	0	M01
6	08:11	08:22	1	START
7	08:22	08:53	0	C05
8	08:53	08:56	0	C01
9	08:56	09:14	0	C05
10	09:14	09:15	0	C07
11	09:15	09:18	1	WORK
12	09:18	09:30	1	WORK
13	09:30	09:36	0	C07
14	09:36	09:38	1	WORK
15	09:38	09:45	0	C08
16	09:45	10:02	1	WORK
17	10:02	10:04	1	WORK
18	10:04	10:06	1	WORK
19	10:06	10:07	1	WORK
20	10:07	10:10	1	WORK
21	10:10	10:16	0	C01
22	10:16	10:22	0	S01
23	10:22	10:25	0	C08
24	10:25	10:27	1	WORK
25	10:27	10:29	0	S01
26	10:29	10:39	1	WORK

27	10:39	10:52	0	S01
28	10:52	10:54	1	WORK
29	10:54	11:08	0	C07
30	11:08	11:12	1	WORK
31	11:12	11:15	0	C07
32	11:15	11:20	1	WORK
33	11:20	11:22	0	M01
34	11:22	11:28	1	WORK
35	11:28	11:30	0	M01
36	11:30	11:34	1	WORK
37	11:34	11:36	1	WORK
38	11:36	11:40	0	S01
39	11:40	11:45	1	WORK
40	11:45	11:48	0	S01
41	11:48	12:00	0	C03
42	12:00	13:00	0	Lunch
43	13:00	13:34	0	C04
44	13:34	13:46	1	WORK
45	13:46	13:48	0	C08
46	13:48	13:51	1	WORK
47	13:51	13:52	0	M03
48	13:52	14:12	1	WORK
49	14:12	14:18	0	C09
50	14:18	14:27	1	WORK
51	14:27	14:32	0	C01
52	14:32	14:37	1	WORK
53	14:37	14:44	1	WORK
54	14:44	14:55	1	WORK
55	14:55	14:58	1	WORK
56	14:58	15:10	1	WORK
57	15:10	15:18	0	C01
58	15:18	15:20	1	WORK
59	15:20	15:20	1	END (NO. 302)
60	15:20	15:25	0	C01
61	15:25	15:25	1	START (NO. 303)
62	15:25	15:33	0	C10

63	15:33	15:35	1	WORK
64	15:35	15:42	1	WORK
65	15:42	15:46	1	WORK
66	15:46	16:25	1	WORK
67	16:25	16:30	0	C01
68	16:30	18:00	1	WORK
69	18:00	18:00	0	END

Activity	Installation of Light Weight Steel Runner & Stud			
Date	2022-09-19			
Modular Unit	No. 302			
Worker	Light Wight Steel Processing Worker			
No.	Work Start	Work End	Status	Issue
1	08:00	08:02	0	C02
2	08:02	08:05	0	S02
3	08:05	08:07	0	S03
4	08:07	08:09	0	C02
5	08:09	08:11	0	M01
6	08:11	08:22	1	START
7	08:22	08:26	0	M03
8	08:26	08:33	1	WORK
9	08:33	08:35	1	WORK
10	08:35	08:41	0	C05
11	08:41	08:54	1	WORK
12	08:54	08:58	1	WORK
13	08:58	09:14	1	WORK
14	09:14	09:15	0	C07
15	09:15	09:18	1	WORK
16	09:18	09:30	1	WORK
17	09:30	09:36	0	C07
18	09:36	09:38	1	Work
19	09:38	09:45	0	C08
20	09:45	10:02	1	Work
21	10:02	10:04	1	Work
22	10:04	10:06	1	Work
23	10:06	10:07	1	Work
24	10:07	10:10	1	Work
25	10:10	10:16	0	C01
26	10:16	10:22	0	S01
27	10:22	10:25	0	C08
28	10:25	10:27	1	Work
29	10:27	10:29	0	S01
30	10:29	10:39	1	Work

31	10:39	10:52	0	S01
32	10:52	10:54	1	WORK
33	10:54	11:08	0	C07
34	11:08	11:12	1	WORK
35	11:12	11:15	0	C07
36	11:15	11:20	1	WORK
37	11:20	11:22	0	M01
38	11:22	11:28	1	WORK
39	11:28	11:30	0	M01
40	11:30	11:34	1	WORK
41	11:34	11:36	1	WORK
42	11:36	11:40	0	S01
43	11:40	11:45	1	WORK
44	11:45	11:48	0	S01
45	11:48	12:00	0	C03
46	12:00	13:00	0	LUNCH
47	13:00	13:05	1	WORK
48	13:05	13:07	1	WORK
49	13:07	13:11	0	C08
50	13:11	13:17	1	WORK
51	13:17	13:20	0	C07
52	13:20	13:22	1	WORK
53	13:22	13:26	0	C08
54	13:26	13:28	1	WORK
55	13:28	13:29	0	C08
56	13:29	13:46	1	WORK
57	13:46	13:48	0	C08
58	13:48	13:51	1	WORK
59	13:51	13:53	0	C06
60	13:53	14:12	1	WORK
61	14:12	14:18	0	C09
62	14:18	14:27	1	WORK
63	14:27	14:32	0	C01
64	14:32	14:37	1	WORK
65	14:37	14:38	0	M03
66	14:38	14:44	0	C01
67	14:44	14:55	1	WORK
68	14:55	14:58	0	C06
69	14:58	15:05	1	WORK

70	15:05	15:18	0	C01
71	15:18	15:20	1	WORK
72	15:20	15:20	1	END (NO. 302)
73	15:20	15:25	0	C01
74	15:25	15:25	1	START (NO. 303)
75	15:25	15:33	1	WORK
76	15:33	15:35	0	C10
77	15:35	15:42	0	C10
78	15:42	15:46	1	WORK
79	15:46	16:25	1	WORK
80	16:25	16:30	0	C01
81	16:30	18:00	1	WORK
82	18:00	18:00	0	END

Activity	Installation of Light Weight Steel Runner & Stud			
Date	2022-09-19			
Modular Unit	No. 302			
Worker	Light Weight Steel Carrying Worker			
No.	Work Start	Work End	Status	Issue
1	08:00	08:02	0	C02
2	08:02	08:05	0	S02
3	08:05	08:07	0	S03
4	08:07	08:09	0	C02
5	08:09	08:11	0	M01
6	08:11	08:22	1	START
7	08:22	08:26	0	M02
8	08:26	08:33	1	WORK
9	08:33	08:35	1	WORK
10	08:35	08:41	0	C05
11	08:41	08:54	1	WORK
12	08:54	08:58	1	WORK
13	08:58	09:14	1	WORK
14	09:14	09:15	0	C07
15	09:15	09:18	1	WORK
16	09:18	09:30	1	WORK
17	09:30	09:36	0	C07
18	09:36	09:38	1	WORK
19	09:38	09:45	0	C08
20	09:45	10:02	1	WORK
21	10:02	10:04	1	WORK
22	10:04	10:06	1	WORK
23	10:06	10:07	1	WORK
24	10:07	10:10	1	WORK
25	10:10	10:16	0	C01
26	10:16	10:22	0	S01
27	10:22	10:25	0	C08
28	10:25	10:27	1	WORK
29	10:27	10:29	0	S01
30	10:29	10:39	1	WORK

31	10:39	10:52	0	S01
32	10:52	10:54	1	WORK
33	10:54	11:08	0	C07
34	11:08	11:12	1	WORK
35	11:12	11:15	0	C07
36	11:15	11:20	1	WORK
37	11:20	11:22	0	M01
38	11:22	11:28	1	WORK
39	11:28	11:30	0	M01
40	11:30	11:34	1	WORK
41	11:34	11:36	1	WORK
42	11:36	11:40	0	S01
43	11:40	11:45	1	WORK
44	11:45	11:48	0	S01
45	11:48	12:00	0	C03
46	12:00	13:00	0	LUNCH
47	13:00	13:05	1	WORK
48	13:05	13:07	1	WORK
49	13:07	13:11	0	C08
50	13:11	13:17	1	WORK
51	13:17	13:20	0	C07
52	13:20	13:22	1	WORK
53	13:22	13:26	0	C08
54	13:26	13:28	1	WORK
55	13:28	13:29	0	C08
56	13:29	13:46	1	WORK
57	13:46	13:48	0	C08
58	13:48	13:51	1	WORK
59	13:51	13:53	0	C06
60	13:53	14:12	1	WORK
61	14:12	14:18	0	C09
62	14:18	14:27	1	WORK
63	14:27	14:32	0	C01
64	14:32	14:37	1	WORK
65	14:37	14:38	0	M03
66	14:38	14:44	0	C01
67	14:44	14:55	1	WORK
68	14:55	14:58	0	C06
69	14:58	15:05	1	WORK

70	15:05	15:18	0	C01
71	15:18	15:20	1	WORK
72	15:20	15:20	1	END (NO. 302)
73	15:20	15:25	0	C01
74	15:25	15:25	1	START (NO. 303)
75	15:25	15:33	1	WORK
76	15:33	15:35	0	C10
77	15:35	15:42	1	WORK
78	15:42	15:46	1	WORK
79	15:46	16:25	1	WORK
80	16:25	16:30	0	C01
81	16:30	18:00	1	WORK
82	18:00	18:00	1	END

Activity	Installation of Window Frame & Door Frame			
Date	2022-09-20			
Modular Unit	No. 303			
Worker	Installation Worker			
No.	Work Start	Work End	Status	Issue
1	8:00	8:02	0	C02
2	8:02	8:05	0	S02
3	8:05	8:09	0	S03
4	8:09	8:23	1	WORK
5	8:23	8:53	1	WORK
6	8:53	9:02	0	C09
7	9:02	9:13	0	C07
8	9:13	9:27	1	WORK
9	9:27	9:45	1	WORK
10	9:45	10:00	1	WORK
11	10:00	10:03	1	WORK
12	10:03	12:00	0	C01
13	13:00	14:00	0	C04
14	14:00	14:02	1	WORK
15	14:02	14:07	0	C09
16	14:07	14:49	1	WORK
17	14:49	15:59	0	C11
18	15:59	16:54	1	WORK
19	16:54	18:00	0	C03

Activity	Installation of Light Weight Steel Runner & Stud			
Date	2022-09-20			
Modular Unit	No. 303 / No. 306			
Worker	Light Weight Steel Installation Worker			
No.	Work Start	Work End	Status	Issue
1	08:00	08:02	0	C02
2	08:02	08:05	0	S02
3	08:05	08:09	0	S03
4	08:09	08:30	1	WORK
5	08:30	08:45	0	C10
6	08:45	08:54	0	M02
7	08:54	08:57	0	C10
8	08:57	09:02	1	WORK
9	09:02	09:04	0	C07
10	09:04	09:05	0	S01
11	09:05	09:23	1	WORK
12	09:23	09:27	0	C05
13	09:27	09:33	1	WORK
14	09:33	09:37	0	C10
15	09:37	09:41	0	M03
16	09:41	10:22	1	WORK
17	10:22	10:28	0	M04
18	10:28	10:34	0	C01
19	10:34	10:48	0	C09
20	10:48	10:53	0	M05
21	10:53	11:32	1	WORK
22	11:32	11:38	0	C01
23	11:38	12:00	0	C03
24	12:00	12:42	0	LUNCH
25	12:42	13:13	1	WORK
26	13:13	13:13	1	END (NO. 303)
27	13:13	13:13	1	START (NO. 306)
28	13:13	13:14	0	M02

29	13:14	13:25	0	C07
30	13:25	13:29	1	WORK
31	13:29	13:31	1	WORK
32	13:31	13:52	1	WORK
33	13:52	13:53	1	WORK
34	13:53	14:05	1	WORK
35	14:05	14:27	0	C01
36	14:27	14:35	0	S01
37	14:35	14:52	1	WORK
38	14:52	15:02	0	C01
39	15:02	15:11	1	WORK
40	15:11	15:15	0	S01
41	15:15	15:20	0	C10
42	15:20	15:24	0	C07
43	15:24	15:55	1	WORK
44	15:55	16:28	0	C01
45	16:28	16:44	1	WORK
46	16:44	17:00	1	WORK
47	17:00	17:05	1	WORK
48	17:05	18:00	0	C03

Activity	Installation of Light Wight Steel Runner & Stud			
Date	2022-09-20			
Modular Unit	No. 303 / No. 306			
Worker	Light Weight Steel Processing Worker			
No.	Work Start	Work End	Status	Issue
1	8:00	8:02	0	C02
2	8:02	8:05	0	S02
3	8:05	8:09	0	S03
4	8:09	8:30	1	START
5	8:30	8:50	1	WORK
6	8:50	8:54	0	M02
7	8:54	9:02	1	WORK
8	9:02	9:04	0	C07
9	9:04	9:05	0	S01
10	9:05	9:23	1	WORK
11	9:23	9:27	0	C05
12	9:27	9:32	1	WORK
13	9:32	9:35	0	M02
14	9:35	9:40	0	M03
15	9:40	9:55	1	WORK
16	9:55	10:07	0	C01
17	10:07	10:13	1	WORK
18	10:13	10:16	0	M02
19	10:16	10:22	1	WORK
20	10:22	10:28	0	M04
21	10:28	10:34	0	C01
22	10:34	10:53	0	C10
23	10:53	11:24	1	WORK
24	11:24	11:38	0	C01
25	11:38	12:00	0	C03
26	12:00	12:42	0	LUNCH
27	12:42	13:13	1	WORK
28	13:13	13:13	1	END (NO. 303)

29	13:13	13:13	1	START (NO. 306)
30	13:13	13:14	0	M02
31	13:14	13:21	1	WORK
32	13:21	13:24	0	C10
33	13:24	14:05	1	WORK
34	14:05	14:13	0	C01
35	14:13	14:15	1	WORK
36	14:15	14:37	0	C01
37	14:37	15:04	1	WORK
38	15:04	15:11	0	C01
39	15:11	15:15	0	S01
40	15:15	15:20	0	C10
41	15:20	15:29	1	WORK
42	15:29	15:42	0	C10
43	15:42	16:28	1	WORK
44	16:28	16:44	1	WORK
45	16:44	17:00	1	WORK
46	17:00	17:05	1	WORK
47	17:05	18:00	0	C03

Activity	Installation of Light Weight Steel Runner & Stud			
Date	2022-09-20			
Modular Unit	No. 303 / No. 306			
Worker	Material Carrying Worker			
No.	Work Start	Work End	Status	Issue
1	8:00	8:02	0	C02
2	8:02	8:05	0	S02
3	8:05	8:09	0	S03
4	8:09	8:30	1	START
5	8:30	8:50	1	WORK
6	8:50	8:54	0	M02
7	8:54	9:02	1	WORK
8	9:02	9:04	0	C07
9	9:04	9:05	0	S01
10	9:05	9:08	1	WORK
11	9:08	9:23	0	C01
12	9:23	9:27	0	C05
13	9:27	9:33	1	WORK
14	9:33	9:38	0	M02
15	9:38	10:13	1	WORK
16	10:13	10:22	0	C01
17	10:22	10:28	0	M04
18	10:28	10:34	0	C01
19	10:34	10:53	0	C10
20	10:53	11:24	1	WORK
21	11:24	11:38	0	C01
22	11:38	12:00	0	C03
23	12:00	12:42	0	LUNCH
24	12:42	13:08	1	WORK
25	13:08	13:13	0	C10
26	13:13	13:13	1	END (NO. 303)
27	13:13	13:13	1	START (NO. 306)
28	13:13	13:14	0	M02

29	13:14	13:21	1	WORK
30	13:21	13:24	0	C10
31	13:24	13:26	1	WORK
32	13:26	13:28	0	C01
33	13:28	14:13	1	WORK
34	14:13	14:22	0	C01
35	14:22	14:37	0	C01
36	14:37	14:51	1	WORK
37	14:51	15:02	0	C01
38	15:02	15:11	1	WORK
39	15:11	15:15	0	S01
40	15:15	15:20	0	C10
41	15:20	15:29	1	WORK
42	15:29	15:42	0	C10
43	15:42	16:44	0	C01
44	16:44	16:50	1	WORK
45	16:50	16:55	0	C01
46	16:55	17:00	1	WORK
47	17:00	17:05	1	WORK
48	17:05	18:00	0	C03

Activity	Installation of 1st Gypsum Board			
Date	2020-09-20			
Modular Unit	No. 302			
Worker	Gypsum Board Installation Worker			
No.	Work Start	Work End	Status	Issue
1	8:00	8:02	0	C02
2	8:02	8:05	0	S02
3	8:05	8:09	0	S03
4	8:09	8:15	0	C10
5	8:15	8:15	1	START
6	8:15	8:35	0	M02
7	8:35	8:36	0	C10
8	8:36	8:38	0	C05
9	8:38	8:41	0	C10
10	8:41	8:43	0	C05
11	8:43	8:47	0	C10
12	8:47	8:48	0	M02
13	8:48	9:02	1	WORK
14	9:02	9:08	0	C05
15	9:08	9:13	0	C11
16	9:13	9:25	0	C01
17	9:25	9:45	0	C06
18	9:45	9:50	1	WORK
19	9:50	9:53	0	C12
20	9:53	10:26	1	WORK
21	10:26	10:28	0	C05
22	10:28	10:52	1	WORK
23	10:52	11:03	0	C01
24	11:03	11:26	0	C10
25	11:26	12:00	0	C03
26	12:00	12:32	0	LUNCH
27	12:32	12:39	0	C05
28	12:39	12:42	0	C12
29	12:42	12:50	0	C05
30	12:50	13:10	0	C01

31	13:10	14:20	0	C08
32	14:20	14:42	1	WORK
33	14:42	14:44	0	M04
34	14:44	15:13	1	WORK
35	15:13	15:16	0	M02
36	15:16	15:20	1	WORK
37	15:20	15:24	0	C07
38	15:24	15:41	1	WORK
39	15:41	15:54	0	C09
40	15:54	15:56	1	WORK
41	15:56	16:22	0	C01
42	16:22	16:32	0	C09
43	16:32	16:43	0	M02
44	16:43	16:58	1	WORK
45	16:58	16:58	1	END
46	16:58	18:00	0	C03

Activity		Unit Moving		
Date		2020-09-21		
Modular Unit		No. 308		
Worker		Forklift Worker		
No.	Work Start	Work End	Status	Issue
1	9:58	10:01	1	START
2	10:01	10:04	0	C10
				END
3	10:04	10:08	1	(To Production Line)
4	10:08	10:10	1	START
5	10:10	10:15	0	C10
6	10:15	10:17	1	(To Spray Zone)

Activity		Installation of Support Anchor		
Date		2022-09-21		
Modular Unit		No. 308 / No. 309 / No. 305		
Worker		Support Anchor Installation Worker		
No.	Work Start	Work End	Status	Issue
1	08:53	9:00	1	START
2	09:00	9:15	0	C07
3	09:15	9:29	1	WORK (Measure)
4	09:29	9:40	1	WORK (Welding)
5	09:40	9:42	0	M04
6	09:42	9:47	1	WORK
7	09:47	9:52	0	M04
8	09:52	9:58	1	WORK
9	09:58	10:00	0	M04
10	10:00	10:15	1	WORK (Welding)
11	10:15	10:32	1	WORK (2nd Anchor)
12	10:32	10:36	0	C07
13	10:36	10:38	1	WORK
14	10:38	10:38	1	END

국 문 초 록

모듈러 건설공법은 기존 건설공법의 한계로 지적되는 낮은 생산성, 안전 문제, 환경문제 등을 극복할 수 있는 대안으로 기대되면서 모듈러 시장은 성장 중이다. 그러나, 실제 건설산업에서 모듈러 건설공법의 채택 비율은 매우 낮으며 프로젝트의 수 또한 극히 드물다. 모듈러 건설 프로젝트 관계자들에 따르면 이러한 현상의 대표적인 원인으로 모듈러 유닛 제작공장의 낮은 생산성을 지적한다. 현장 시공과 공장 생산이 동시에 진행되는 공법 특성상 공장의 생산능력이 현장의 시공 속도에 미치지 못한다면 공사 기간이 지연되며 이는 공사비 문제로 직결된다. 따라서 실제 건설산업에서 모듈러 공법의 확산을 기대하기란 현재까지는 어려운 실정이며, 모듈러 유닛 제작공장에 대한 생산성 개선이 선행되어야 하는 상황이다. 기존 전통적인 건설공법의 생산성 연구는 많이 이루어져 왔으나, 모듈러 유닛 생산에 대한 생산성 연구는 거의 이루어지지 않았다. 또한, 수행된 모듈러 프로젝트의 수가 극히 드물기 때문에 모듈러 공장의 생산성 개선을 위해 참조할 데이터 역시 극히 드물다. 이러한 이유로 아직까지도 모듈러 유닛 생산라인이 지연되고 중단되는 원인에 대한 파악이 어려우며, 각 생산공정별로 어떠한 활동이 얼마만큼의 작업중단 혹은 지연이 발생하는지 또한 정량적인 파악이 어려운 실정이다. 모듈러 유닛 생산의 대부분의 공장은 유닛은 고정되고 작업자가 팀을 이루어 이동하며 작업하는 방식인 유닛 고정형 생산 방식을 채택하고 있다. 본 연구는 이러한 유닛 고정형 생산방식을 따르면서 국내에서 가장 규모가 크고 가장 높은 층수로 최초로 진행되는 중고층 모듈러 공동주택 프로젝트를 작업 생산성 모니터링 대상 프로젝트로 선정하여 사례연구를 진행하였다. 선정 프로젝트의 현장 관측을 통해 모듈러

공장 작업 생산성 데이터를 1분 단위로 측정했으며, 작업자들의 각 작업 수준까지 분류되어 데이터가 수집되었다. 가치를 저해시키는 작업 중 불필요한 활동을 생산성 개선을 위해 제거해야 할 대상인 낭비로 정의하고 각각의 공종에서 낭비가 얼마나 발생했는지를 정량적으로 분석했다. 모듈러 생산성 개선과 관련된 대부분의 연구들은 모듈러 공장의 생산라인 자체를 변경하거나 스케줄을 변경하는 등 거시적인 차원에서 공장의 생산성을 향상시킬 수 있는 관리 방안들을 제안해왔다. 그러나, 대부분 유닛 생산기간이 매우 짧은 저충형 모듈러 프로젝트 데이터를 활용하거나, 특성이 다른 전통적인 건설 프로젝트 데이터를 사용하여 해당 기술을 실제 현장에 적용하는데 많은 어려움이 존재한다. 본 연구는 현재까지도 작업자가 중심이 되는 유닛 생산 방식을 고려하여 작업자를 기반으로 한 중고충형 모듈러 프로젝트에 대한 공종별 작업시간 데이터를 수집하고, 이를 바탕으로 낭비를 제거함으로써 생산성 향상을 위한 주요 관리 요소 도출 및 작업 생산성을 향상시킬 수 있는 관리방안을 식별한다. 본 사례연구를 통해 식별된 주요 관리요소들은 모듈러 프로젝트의 확산 및 고충화를 위해 나아갈 수 있는 기초자료를 제공하며, 공장의 생산성 향상을 위해 모듈러 이해관계자들이 참고할 수 있는 기초자료로 활용될 수 있다.

주요어 : 모듈러 건축; 모듈러 유닛 제작 공장; 작업 생산성; 사례연구; 현장 관측; 린 이론; 낭비

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