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Article

# Quantitative Analysis of Waiting Length and Waiting Time for Frame Construction Work Activities using a Queue Model; Focusing on Korean Apartment Construction

Jin-Won Kim <sup>1</sup>, Nam-Hyuk Ham <sup>2,\*</sup> and Jae-Jun Kim <sup>3</sup>

<sup>1</sup> Department of Architectural Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, 04763, Korea; trustguys@gmail.com

<sup>2</sup> Department of Digital Architecture and Urban Engineering, Hanyang Cyber University, 220, Wangsimni-ro, Seongdong-gu, Seoul 04763, Korea; nhham@hycu.ac.kr

<sup>3</sup> Department of Architectural Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, 04763, Korea; jjkim@hanyang.ac.kr

\* Correspondence: nhham@hycu.ac.kr; Tel.: +82-2-2290-0861

**Abstract:** The frame construction of an apartment complex that consists of multiple buildings encounters various uncertainties, owing to the complex relationships among units of work. Currently, the period of such a construction is calculated based on the number of floors of the highest building in the complex. This study quantitatively analyzes an apartment frame construction period using a queue model and evaluates the validity of the estimated period. In this regard, a methodology is proposed for analyzing the construction period by applying the concept of a customer and a server. A case study on the duration of an apartment frame construction is conducted with Korea Land and Housing Corporation, which has supplied the largest number of apartments in South Korea. It was found that the stable state of a queue system was observed when the rate of server utilization was applied to the basement and aboveground floors. However, a stable state was not reached on the ground floor. This study includes non-working days in its calculation and quantitatively analyzes uncertainty factors during construction. Therefore, the findings can be practically utilized to quantitatively plan the durations of work units in an apartment frame construction.

**Keywords:** Frame Construction; Multiple Buildings; Construction Period; Uncertainty Factors; Queue Model

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## 1. Introduction

Construction periods are generally determined during the planning stage to provide cost and schedule estimates [1]. Estimation accuracy is directly related to the success or failure of a project [2]. However, it is difficult to account for the uncertainty of construction, given that the work is incredibly complex and relies on dynamic environments [3]. Various work units, such as the installation of rebar, forms, electricity, communication systems, and concrete, can be conducted simultaneously in apartment complexes that consist of multiple buildings. For this reason, the lead-lag relationship between unit works is significantly complicated. Additionally, because the entirety of frame construction is performed outside, many more types of uncertainty exist because of weather. Construction methods, materials used, and human resources are volatile. Nevertheless, construction periods must be estimated based on units of work and planned resources [4]. Moreover, non-working days, which can occur due to work-site conditions, planned days off, and weather, must also be considered [5].

An apartment frame construction period is calculated based on a cycle per floor of the tallest building in the complex, regardless of project scale. However, this calculation method cannot properly reflect project scale, construction methods, work units, and

human resources. Accordingly, delays are common, and they increase project cost and can result in a decrease in the quality of the finishing work. Hence, anticipated rent income is delayed.

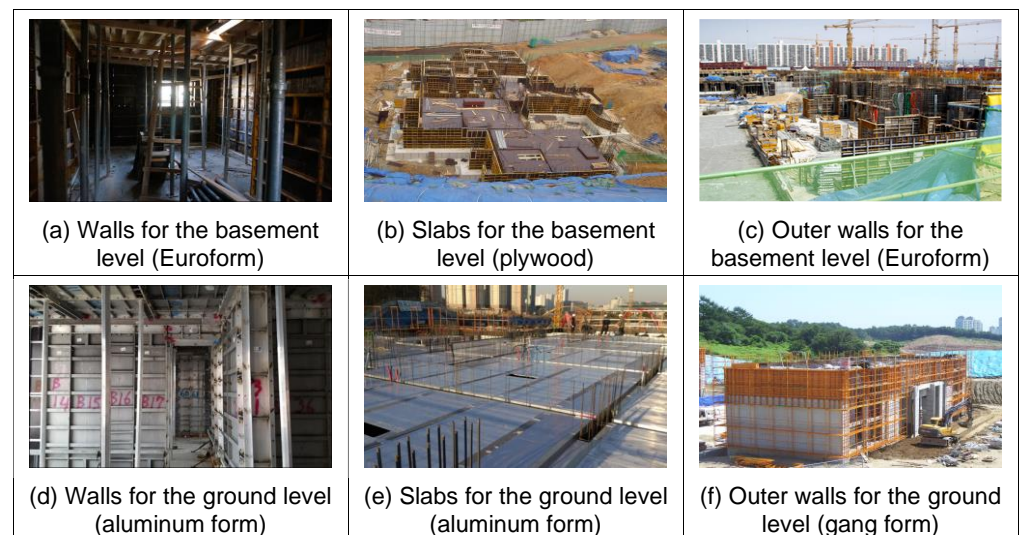
Existing estimation methods mainly apply probabilistic techniques to calculate an apartment frame construction period, which remains difficult because of the uncertainty factors [5-9]. These methods increase estimation accuracy to a certain extent, but they are unlikely to be practically applied, owing to the difficulty in verifying ground-truth estimations [10].

This study quantitatively analyzes an apartment frame construction period, which is regarded as a multi-project type. It reviews the validity of the period based on the tallest building in the complex. Notably, methods and resources vary according to construction sections. In this regard, floors are classified as basement, ground, and typical (i.e., second-to-top) for analysis. Furthermore, the duration of construction sections is quantitatively examined in consideration of the work units and resources required. Doing so, this study optimizes the apartment frame construction period estimation method to better support project planning.

## 2. Literature Review

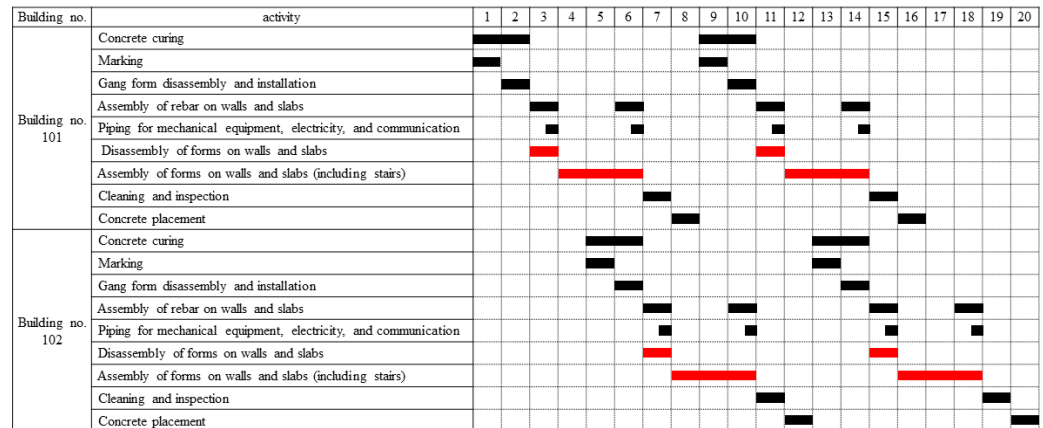
### 2.1 Characteristics of Apartment Frame Construction

Frame construction comprises unit works of marking, rebar assembly, forms, slabs, electrical wiring, communication plants, machinery, and concrete. Form assembly accounts for the highest proportion of apartment frame construction and requires a variety of materials and construction methods according to the planned sections, as shown in Fig. 1. A conventional construction method uses euro form and plywood in the basement floor of an apartment, and a system construction method based on gang and aluminum forms is applied to the ground floor. After setting these forms on the ground floor, the same work is repeated upward per floor. Thus, the cycle per floor is significantly shorter for the ground floor than for the basement.



**Figure 1.** Types of formwork according to floors in apartment frame construction.

A typical floor construction plan is established mainly based on formwork, which accounts for a large proportion of the entire project, as shown in Fig. 2. The cycle per floor is generally 8 days. However, based on working days vs. non-working days, 10 to 12 days are generally required. Hence, the formwork crew is generally tasked with three simultaneously buildings to minimize idle time and to facilitate efficiencies.



**Figure 2.** Construction planning for the typical floor in apartment frame construction

Therefore, the construction period for apartments consisting of two or more buildings should be calculated in consideration of a lead-lag relationships among work units, the number of actual working days, the number of non-working days, resource allocation, and idle time.

### 2.2. Uncertainty Factors in Apartment Frame Construction

Generally, factors affecting a construction period include design, labor, materials, equipment, subcontracts, weather, planning, and execution [11]. These factors can cause delays and interruptions owing to the mentioned uncertainties [12]. McTague and Jergas [13] reported that 35 % of the entire work time was wasted because of delays and that preparation time accounted for 28 % of the work time. This implies that actual working time occupies only 50 % of the entire work period. Formwork accounts for the other half [14]. Thus, optimization should account for both.

### 2.3. Research Methods for Quantifying Uncertainty

Most apartment frame constructions apply repeated and sequential methods. When a certain work is delayed, adjacent work is also delayed until the previous works are finished. This phenomenon is exacerbated for framing jobs, which occur outdoors. Past studies optimized apartment frame construction period estimation by focusing on the uncertainty factors. Specifically, probabilistic methods were used to apply weather factors [5,6] and human resources [7], relying on support vector machine (SVM) algorithms and artificial neural networks (ANNs) [8,9].

Jung [5] developed a model that estimates high-rise building construction delays according to weather conditions (e.g., temperature, wind velocity, and precipitation). Lee [6] presented a model that could estimate construction periods based on the number of floors in frame construction alongside regional climate conditions and expert opinions. These methods could unfortunately only be applied to projects in which the same works were consecutively repeated (e.g., roads and typical framed floors).

Leu [7] proposed a model for integrating concepts of time-cost trade-offs and resource allocation, and developed a method for optimizing resource elements during process planning. However, this method could be used only for construction works that applied a line-of-balance technique. This technique is unlikely to be used in multi-projects, as for apartment frame construction.

Petruseva et al. [8] proposed an SVM-based learning algorithm trained with contract and price data of 75 projects to increase estimation accuracy. Golizadeh et al. [9] presented an ANN model that estimated a construction period that considered the structural elements of frame construction. Although these methods quantitatively estimated construction periods using machine-learning techniques, they were limited in that specific processes for deriving analytic results could not be precisely verified (i.e., the ground-truth problem).

Therefore, workflow management (WFM) techniques, which account for lead time, wait time, service time, and resource utilization [15], have been used. A queueing theory is generally applied to analyze performance, because it is suited for the mathematical processes required. Moreover, it can be utilized to effectively examine the network workflow of various activities [16].

Queueing theory was developed to support examinations of various waiting cases that can be practically observed. Fig. 3 diagrams this model. This theory can be used to quantitatively analyze the appropriate scale of a service facility based on probabilities related to customer arrival time, service time, and idle time. Customers individually enter a queueing system to receive a service, and a queue occurs when a customer who reaches the queue system waits without receiving a service. Generally, more than one single server provides services to customer, and the customer leaves the queue system after service is completed. Eventually, the queue is eliminated. This queue model can be applied in both daily life and various professional fields, such as computer programming, networking, medicine, and banking [17]. In the construction field, a related study was conducted to apply the concept of customer–server queueing with regards to construction equipment for concrete placement and excavation [18].

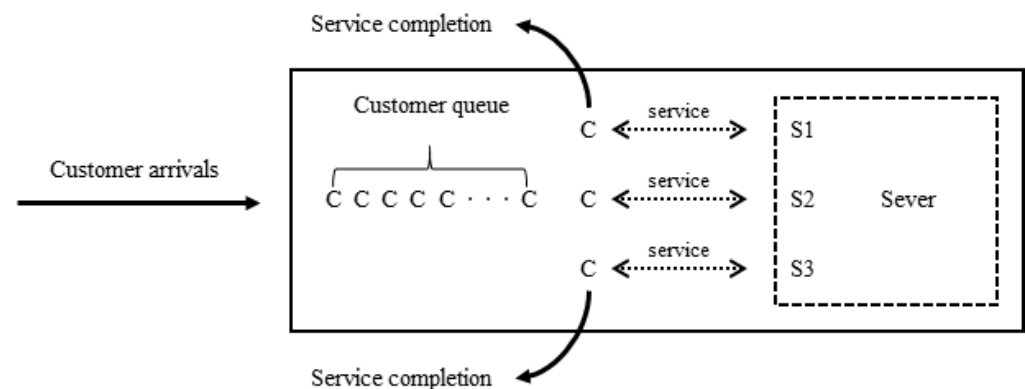


Figure 3. The queue system.

### 3. Research Method

As noted, work units per floor based on their lead–lag relationships are repeated for apartment frame construction. Thus, wasted time must be quantitatively analyzed to optimize period estimations. A queue model can quantitatively analyze waiting times for customers waiting for a service. This study applies the concept of customer–server queue relationships to estimating apartment frame construction.

#### 3.1. Definition of Customer and Server

Table 1 lists the details of the queue model established to quantitatively analyze an apartment frame construction period according to construction sections. In this model, floors are classified as basement, ground, and typical (i.e., second and higher) according to the construction methods applied to each type of formwork. A customer is a work unit per construction section, and a server reflects the work crew performing the unit of work. Because the customer and the server are determined based on the amount of work and the number of teams, productivity data related to a target work unit can be utilized to estimate the apartment frame construction period. Moreover, a construction period for the target work unit can be shortened via the adjustment of the number of teams (servers). Works for the basement floor are classified as rebar works and formworks, which account for half the entire work. Works for the ground floor are classified as gang- and aluminum-form setting. On a typical floor, the same works are repeated. Thus, all work units performed for concrete placement on each floor are considered.

**Table 1.** Establishment of the queue model

Floor	Form method	Customer (work quantity)	Server (working group)	Code
basement	euro form & ply-wood	area of the form work	carpenter	Ba
		weight of rebar	rebar worker	Bb
ground	gang form & aluminum form	area of the form work	gang form worker	Ga
		length of gang form	carpenter	Gb
typical		duration of concrete pouring per floor	carpenter	Ta

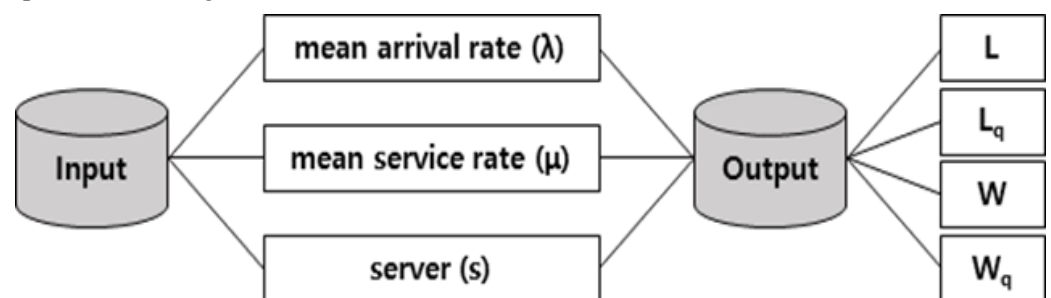
### 3.2. Establishment of a Basic Performance Scale

In the queue system, inter-arrival times account for the time between the arrival of a customer and that of another. When arrival data are sufficiently collected, the average number of customers per unit time can be estimated, giving the mean arrival rate,  $\lambda$ . Because the time when customers reach the queue is irregular and varies depending on conditions, the probability distribution for inter-arrival times in most models take on an exponential distribution. Thus, an estimated mean inter-arrival time for queue is defined as  $1/\lambda$ .

Service time in the queue system refers to the time from which a customer begins receiving the service until the service is completed. Assuming that a server works without a break, the mean service rate is the average number of customers who receive completed services from the server per unit time,  $\mu$ . Generally, service time differs according to service types requested. Thus, the probability distribution takes the form of an exponential distribution, and the estimated mean service time is  $1/\mu$ .

Performance criteria for the queue system can be derived based on the mean arrival rate, the mean service rate, and the server, as shown in Fig. 4. Performance criteria are classified using the following four criteria according to whether only customers waiting for the queue system are considered, or whether a customer receiving services in the queue system is also considered.

In Fig. 4,  $L$  is the mean number of customers being accessed in the queue system, including any customer receiving a service.  $L_q$  is the mean number of customers waiting in a queue, except one receiving a service.  $W$  is the mean waiting time of each customer in the queue, including service time.  $W_q$  is the mean waiting time of each customer in the queue, excluding service time.

**Figure 4.** Input and output variables in the queue model.

### 3.3. Performance-scale Analysis Method

An analysis of performance criteria for the queue system requires basic information on the amount of work being performed according to construction sections, an estimated construction period, a practical construction period, and the number of work crew. Based on such information, input variables of the queue model, such as mean arrival rate ( $\lambda$ ), mean service rate ( $\mu$ ), and server ( $s$ ), can be identified. Equations are defined as follows:

$$\lambda = (\text{entire amount of work for a customer (unit work)}) \setminus /$$

$$\text{(estimated construction period for a service (work)),} \quad (1)$$

$$\mu = \frac{\text{(entire amount of work for a customer (unit work))}}{\text{(practical construction period for a service (work))}}, \quad (2)$$

$$s = \text{(number of work group input according to unit works)}. \quad (3)$$

Little's formula is applied to identify basic performance criteria for the queue model, and the relationship between  $L$  and  $W$  is defined with Eq. 4. This equation can also be applied to a relation between  $L_q$  and  $W_q$ . When one of  $L$ ,  $L_q$ ,  $W$ , or  $W_q$  is analyzed, the other performance criteria can be easily calculated. Those that can be used to analyze a fundamental state of a service are determined through the following equation.

Other than basic performance criteria, the probability related to a state of the queue system, such as the number of customers being accessed in the queue system and waiting time, can also be analyzed. When the rate ( $\rho$ ) of server utilization is high, the state of the queue system becomes worse. When waiting time increases, the point of a server input that provide the service can be delayed. Thus, the appropriate scale of servers can be determined via the probabilistic analysis of time in the queue system to optimize an apartment frame construction period.

$$L = \lambda W, \quad (4)$$

$$P_0 = \frac{1}{\left( \sum_{n=0}^{s-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s! (1 - \lambda/s\mu)} \right)}, \quad (5)$$

$$L_q = \frac{(P_0 (\lambda/\mu)^s \rho)}{s! (1 - \rho)^2} = \frac{(P_0 \lambda^{s+1})}{(s-1)! \mu^{s-1} (s\mu - \lambda)^2}, \quad (6)$$

$$W_q = L_q / \lambda, \quad (7)$$

$$W = W_q + 1/\mu. \quad (8)$$

#### 4. Case Study

Figure 5 shows an Excel-based construction-period estimation tool, which has been applied to apartment construction projects ordered by Korea Land and Housing Corporation (LH). This tool can be easily used, because it calculates the construction period from basic project information (e.g., region, dates, households affected, and number of floors). However, it exhibits limited performance regarding the uncertainty that can occur during construction, given that it calculates the period based on the number of floors of the highest building regardless of the project scale, as shown in Fig. 6. Thus, the construction period according to construction sections and the entire amount of work was quantitatively analyzed based on performance data of apartment frame construction projects ordered by LH.

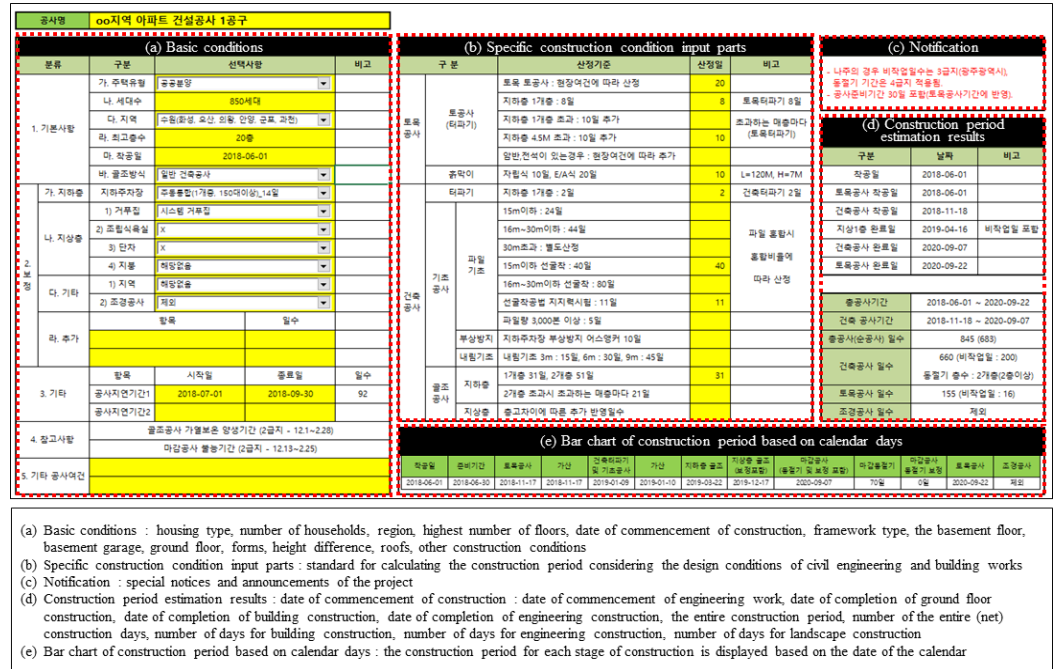


Figure 5. Construction period calculation tool used by LH.

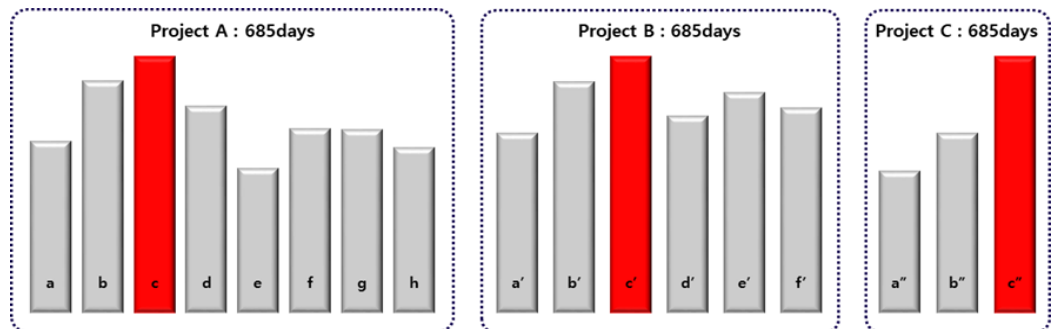


Figure 6. Examples of construction period calculation results for projects ordered by LH.

4.1. Overview of a Construction Period

Table 2 indicates details of the most common project type executed by LH, which comprises eight apartment buildings of 450 households with areas of exclusive use of 59 or 84 m<sup>2</sup>. The entire construction period for this project was planned for 846 days, and the apartment frame construction period was planned for 336 based on the number of floors of the highest building (19), and non-working days were considered. The construction periods for the basement floor, the ground floor, and the typical floor were planned to take 84, 26, and 226 days (12.5 days per floor), respectively.

4.2. Data Collection and Classification

Table 3 displays the data of planned processing tables, concrete-placement management reports, work histories, and interview results, which were used for analysis. The amount of work is the sum of work units per floor, and a work proportion is the ratio of a work unit according to construction sections based on the entire amount of work. A construction period estimation tool developed by LH was used to calculate the estimated frame construction period. Construction periods per floor were multiplied by work proportions of each work unit to calculate estimated construction periods according to the construction sections. Regarding the practical frame construction period, that of concrete placement management reports was analyzed and multiplied with the work

proportion. Information on daily productivity, and work-crew formation was obtained from interviews with a responsible LH worker.

Table 4 shows the result of analyzing apartment frame construction performance based on unit works in consideration of construction periods. Ratios ( $\rho = \lambda / s\mu$ ) of server utilization on basement and typical floors satisfy condition ( $\rho < 1$ ), where a queue can reach a stable state. However, the  $\rho$  value for the basement floor was calculated to be 0.82, indicating that the server was fairly busy. In other words, when an uncertainty factor occurs during a construction stage, it can significantly create a delay for the entire job. The ratio of server utilization on the ground floor was calculated as 1.27, which failed to satisfy the condition of queue stability. The ratio of server utilization on a typical floor was calculated to be 0.39. It was analyzed that the server stayed fairly stable, because 61 % can participate in works other than the typical floor.

**Table 2.** Overview of construction for a project selected as an analysis target in this study.

Classification	Overview
Location	Geumgok-dong, Gwonseon-gu, Suwon-si, Gyeonggi-do
Construction period	846 days (336 days for frame construction)
Construction cost	44,996,785,000 won (KRW)
Site area	27,804 m <sup>2</sup>
Gross floor area	65,678 m <sup>2</sup>
Number of buildings	8
Highest number of floors	19
Number of households	450
Supply type	sale
Building to land ratio	20.42 %
Floor area ratio	169.88 %

**Table 3.** Data collection and classification.

Floor	Code	Amount of work	Work proportion	Duration (days)		Daily productivity
				Estimated	Executed	
basement	Ba	12,821 m <sup>2</sup>	0.48	40.65	66.29	12.39 m <sup>2</sup> /man-day
	Bb	325 ton	0.29	24.39	39.77	1.22 ton/man-day
ground	Ga	11,738 m <sup>2</sup>	0.33	8.67	33.00	22.96 m <sup>2</sup> /man-day
	Gb	1,101 m	0.28	7.22	27.50	27.52 m/team-day
typical	Ta	120 F	1.00	226	266	0.45 f/day

**Table 4.** Performance analysis indices for apartment frame construction periods.

Code	Mean arrival rate ( $\lambda$ )	Mean service rate ( $\mu$ )	Number of sever (s) (man/s)	Server utilization ( $\rho = \lambda / s\mu$ )	Server efficiency (1- $\rho$ )
Ba	152.63	93.59	2(13/1)	0.82	0.18
Bb	13.33	8.17	2(12/1)		
Ga	1,354.39	355.70	3(15/1)	1.27	-
Gb	152.45	40.04	3(5/1)		
Ta	0.53	0.45	3(15/1)	0.39	0.61

#### 4.3. Construction Period Analysis According to Concrete Placement Days



Figure 7 shows the result of apartment construction periods per floor based on concrete placement days. Specifically, this result was examined according to the minimum construction period, the maximum construction period, the mean construction period, and the estimated construction period. The estimated apartment frame construction period per floor is generally located between the minimum and maximum frame construction periods. However, the estimated construction period for the ground floor, which was calculated as 26 days, was significantly lower than the executed construction period (46 days min and 70 days max). Moreover, when comparing the minimum construction period and maximum construction period for each floor of eight buildings, the deviation of the construction period for each floor of the framework was analyzed to be 40 days underground, 24 days on the first floor, and 29 days on the second floor. This result verifies that idle time occurred, owing to various uncertainty factors during the initial construction stage. It was analyzed that such phenomenon occurred because of the following reason. In apartment frame construction, a work-crew team is responsible for two or more buildings; thus they sequentially perform the work. Consequently, waiting time is generated depending on on-site conditions, leading to delays in the construction period. In fact, the mean construction period for the basement floor in eight buildings was shorter than the estimated construction period. On the other hand, the completion point of the entire work for the basement floor was delayed 137 days compared with the estimated completion point. Furthermore, the completion point of the entire work for the ground floor, characterized by the setting of aluminum and gang forms, was also delayed by 99 days compared with the estimated end point. Based on this, it can be shown that an estimated apartment construction period, which is calculated based on the number of floors of the highest building selected through a critical-path analysis, is merely a guideline for project ordering. In other words, this estimated period cannot be effectively used to organize work crews or establish process plans. Therefore, conditions of a target project, such as the entire amount of work, resource inputs, and productivity, should be comprehensively considered to optimize apartment frame construction period estimation.

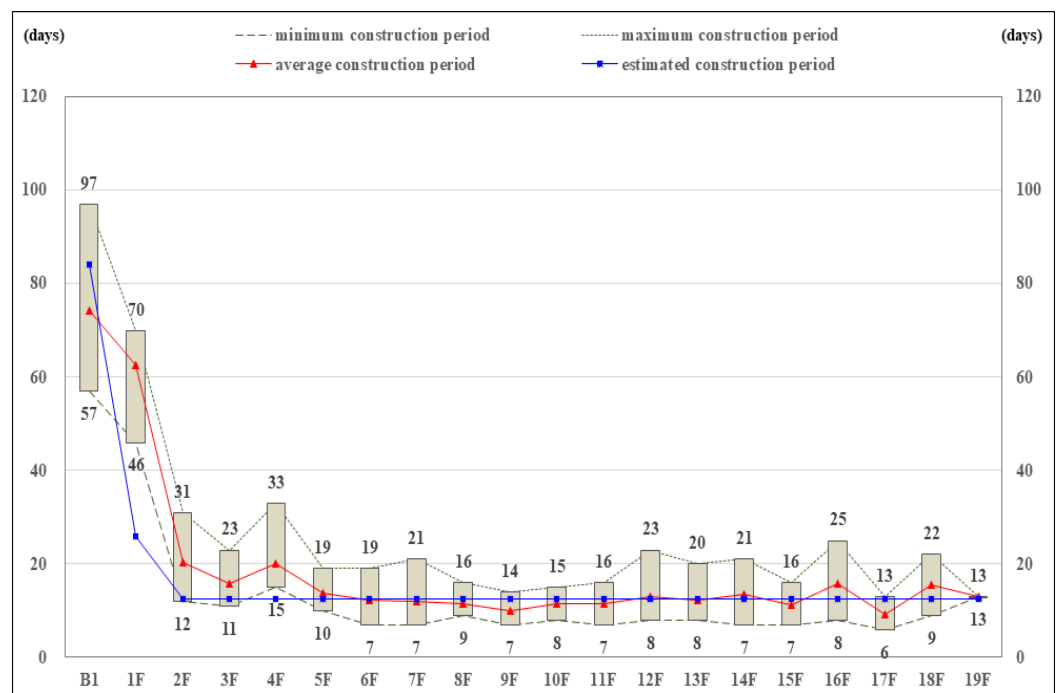


Figure 7. Analysis results of construction periods based on concrete placement reports.

#### 4.4. Construction Period Analysis based on a Queue Model

Table 5 shows the result of analyzing the waiting length and the waiting time during apartment frame construction periods according to floors based on performance analysis indices. The mean arrival rate and the mean service rate for apartment frame construction were calculated based on construction periods according to floors and the number of working teams according to work units. For this reason, waiting length was calculated to be consistent for all floors. Thus,  $L$  and  $Lq$ , consistent to waiting length, were converted into work amounts (e.g.,  $m^2$ /days, ton/days, and floor/days) via the multiplication of the number of work crews for a corresponding work unit and daily productivity.  $W$  and  $Wq$ , consistent with waiting time, were converted into time (h) through multiplication with 9 h, the mean working time per day in apartment frame construction.

$L$ ,  $Lq$ ,  $W$ , and  $Wq$  for the formwork (Ba) on the basement floor were calculated to be 784  $m^2$ , 521  $m^2$ , 0.3 h, and 0.2 h, respectively.  $L$ ,  $Lq$ ,  $W$ , and  $Wq$  for rebar work (Bb) were calculated to be 75 tons, 50 tons, 3.2 h, and 2.2 h, respectively. A ratio ( $\rho$ ) of server utilization for frame construction on the basement floor was calculated to be 0.82, indicating that the server was fairly busy and that a queue requiring ~3 h was needed for rebar work (Bb). Because a queue is unlikely to occur in a system for formwork (Ba) on the basement floor, it can exert significant effects on the execution point of the follow-up rebar work (Bb). Therefore, it was analyzed that schedule management for formwork should be performed to prevent a delays on the basement floor.

A ratio of server utilization on the ground floor was calculated to be 1.27, which failed to satisfy the condition ( $\rho < 1$ ), where a queue can reach a stable state. This phenomenon occurred because of the following reasons. First, a construction period for the ground floor was estimated to be 26 days, whereas it was practically delayed to be 99. Moreover, various uncertainty factors that might occur during a construction stage were not reflected in the process of estimating an apartment frame construction period. Based on this, it can be concluded that the period required for setting a gang form and an aluminum form should be sufficiently reflected to optimize the construction period for the ground floor.

$L$ ,  $Lq$ ,  $W$ , and  $Wq$  for work (Ta) based on a cycle on the typical floor were calculated to be 8.5 f, 5.9 f, 1.4 h, and 0.4 h, indicating that waiting durations were partially generated. However, because the  $\rho$  value was calculated to be 0.39, it was analyzed that the server was in a fairly stable state. This phenomenon was observed, because delayed construction periods for the basement floor and the ground floor also led to a delay in execution of work on a typical floor. Therefore, it was evaluated that the estimated construction period for the typical floor was appropriately calculated.

**Table 5.** Analysis results of basic performance criteria on construction periods per floor.

	Analysis results				Unit conversion			
	L	Lq	W	Wq	L	Lq	W	Wq
Ba(s=2)	4.87	3.24	0.03	0.02	784 $m^2$	521 $m^2$	0.3 h	0.2 h
Bb(s=2)	4.87	3.24	0.36	0.24	75 ton	50 ton	3.2 h	2.2 h
Ga(s=3)	-	-	-	-	-	-	-	-
Gb(s=3)	-	-	-	-	-	-	-	-
Ta(s=3)	1.26	0.88	2.38	0.16	8.5 f	5.9 f	1.4 h	0.4 h

## 5. Discussion

This study examined the differences between an estimated frame construction period for an apartment complex consisting of multiple buildings and its practical period to determine the degree of accuracy using a quantitative analysis. Existing studies [5,6] on analyzing apartment frame construction periods adopted probabilistic methods to solve issues related to uncertainty. This study is different from those in that it quantitatively

analyzed an estimated construction period reflecting not only weather conditions but also non-working days and idle time. Moreover, it inspected the validity of an estimated construction period according to construction sections by classifying an analysis range for a construction period using basement, ground, and typical (i.e., second and above) floors in consideration of applied construction methods, materials, and work-crew formation. Additionally, this study quantitatively analyzed waiting durations according to construction sections through the application of a queue model, which can be further utilized to effectively distribute resources in consideration of the scale of the apartment frame construction. The most common project executed by LH, which has supplied the largest number of apartments in South Korea, was selected as a case study. Representativeness of samples is suspect, given that construction period analysis was performed based on only a single project. However, the practical construction period for the ground floor analyzed in this study was delayed by ~350 % over the estimation. Thus, it is expected that similar results are typical of other projects. Based on the results of this study, it can be shown that an estimated construction period for the ground floor should be adjusted through sufficient consideration of the period required for on-site delivery of gang- and aluminum-form materials, material inspections, settings, and quality confirmations. Furthermore, this study is significant in that its findings can be used to practically evaluate the validity of construction periods to further optimize estimated construction periods via constant feedback.

## 6. Conclusion

The frame construction period for apartments being built in South Korea was determined based on the number of floors of the highest building in a target apartment complex, regardless of the scale or the entire scope of work. Various uncertainty factors that can occur during a construction stage can cause delays and force consecutive work to be rescheduled. Because of these and other uncertainty factors, unnecessary idle time is generated during construction. This study, in turn, quantitatively analyzed a practical construction period using a case study to examine how accurately an apartment frame construction period was estimated. The analysis range for apartment frame construction was classified as basement, ground, and typical (i.e., second and above) floors in consideration of the applied construction methods, materials used, and the number of work crew inputs. A queue model was utilized to calculate performance criteria related to waiting durations. Performance data on estimated and practical construction periods, work crews according to unit works, and daily productivity were collected and used for analysis.

This study is distinguished from extant ones in that it evaluated the validity of a construction period according to construction sections using a quantitative analysis, unlike the other studies that estimated periods based on only empirical data and monitoring results. Furthermore, the results of this study can be used to develop guidelines for establishing process planning, because waiting length and waiting time according to unit works in apartment frame construction can be quantitatively identified from a practical perspective. Additionally, the concept of a customer-server relationship, which is derived from queueing theory, applies to the analysis of construction periods for various projects, given that relevant data can be easily collected.

This study has a limitation in that a practical apartment frame construction period was analyzed based on only a single project. Thus, further research is needed to quantitatively analyze practical construction durations and to optimize the queueing model.

## 7. Patents

**Author Contributions:** Conceptualization, J.W. and N.H.; methodology, J.W. and N.H.; validation, J.W.; formal analysis, J.W. and N.H.; investigation, J.W.; data curation, J.W.; writing—original draft preparation, J.W.; writing—review and editing, N.H. and J.J.; visualization, J.W.; supervision, J.J. All authors have read and agreed to the published version of the manuscript.

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## References

1. Sonmez, R. Conceptual cost estimation of building projects with regression analysis and neural networks *Can. J. Civ. Eng.* 2004, 31, 677–683.
2. Bayram, S. Duration prediction models for construction projects: In terms of cost or physical characteristics? *KSCE J. Civ. Eng.* 2017, 21, 2049–2060.
3. Mulholland, B.; Christian, J. Risk assessment in construction schedules. *J. Constr. Eng. Manag.* 1999, 125, 8–15.
4. Lu, M.; Li, H. Resource-activity critical-path method for construction planning. *J. Constr. Eng. Manag.* 2003, 129, 412–420.
5. Jung, M.-H.; Park, M.-S.; Lee, H.-S.; Kim, H.-S. Weather-delay simulation model based on vertical weather profile for high-rise building construction. *J. Constr. Eng. Manag.* 2016, 142, 04016007.
6. Lee, H. S.; Shin, J. W.; Park, M. S.; Ryu, H.-G. Probabilistic duration estimation model for high-rise structural work. *J. Constr. Eng.* 2009, 135, 1289–1298.
7. Leu, S. S.; Hwang, S. T. Optimal repetitive scheduling model with shareable resource constraint. *J. Constr. Eng. Manag.* 2001, 127(4), 270–280.
8. Petrusseva, S.; Zileska-Pancovska, V.; Zujo, V. Predicting construction project duration with support vector machine. *Int. J. Res. Eng. Technol.* 2013, 2, 12–24.
9. Golizadeh, H.; Sadeghifam, A. N.; Aadal, H.; Majid, M. Z. A. Automated tool for predicting duration of construction activities in tropical countries. *KSCE J. Civ. Eng.* 2016, 20, 12–22.
10. Erharter, G. H.; Marcher, T. On the pointlessness of machine learning based time delayed prediction of TBM operational data. *Autom. Constr.* 2021, 121, 103443.
11. González, P.; González, V.; Molenaar, K.; Orozco, F. Analysis of causes of delay and time performance in construction projects. *J. Constr. Eng. Manag.* 2014, 140, 04013027.
12. Castro-Lacouture, D.; Süer, G. A.; Gonzalez-Joaqui, J.; Yates, J. K. Construction project scheduling with time, cost, and material restrictions using fuzzy mathematical models and critical path method. *J. Constr. Eng. Manag.* 2009, 135, 1096–1104.
13. Sloodman, T. Planning of mega-projects: Influence of execution planning on project performance. 2007.
14. Hewage, K. N.; Ruwanpura, J. Y. Carpentry workers issues and efficiencies related to construction productivity in commercial construction projects in Alberta. *Can. J. Civ. Eng.* 2006, 33, 1075–1089.
15. Zhuge, H.; Cheung, T.; Pung, H. A timed workflow process model. *J. Syst. Software.* 2001, 55, 231–243.
16. Truong, N. K. V.; Choi, Y.; Kim, I.; Shin, S.; Hwang, W. J. A probabilistic approach to workflow time analysis for business process management. *Int. J. Hum. Soc. Sci.* 2009, 5, 811–815.
17. Shanmugasundaram, S.; Umarani, P. Queuing theory applied in our day to day life. *Int. J. Sci. Eng. Res.* 2015, 6, 534–541.
18. Teknomo, K. Queuing rule of thumb based on M/M/s queuing theory with applications in construction management. *Civ. Eng. Dimens.* 2012, 14, 139–146.