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# Optimal management plan through ready-mix concrete placement and transportation time

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**Abstract**

**Background/Objectives: RMC orders are made based on the experience of on-site managers, optimal management of RMC is difficult. This leads to a drop in quality management and productivity of RMC. Therefore, optimal RMC management plans are needed rather than on-site experience**
**Methods/Statistical analysis: This study analyzed research on simulations for improving construction productivity conducted in various architectural fields to produce simulations for the productivity and quality management of RMC. To make the simulation, a general expression that can predict placement time through discharge per hour of pump cars and concrete quantity of the area to be placed is deduced. By applying the simulation RMC entrance time and placement time are analyzed to verify by comparing with simulation results.**
**Findings: Time difference is predicted using this to find the general expression of the placement time. Through this, it is possible to predict the RMC order time. The RMC movement time is classified to the batcher plant to the site entrance, site entrance to the RMC standby location, and RMC standby location to the pump car to determine the route, and the general expression is used to find the time needed for the route. Each RMC is numbered through the produced simulation to find the optimal number of RMC on the site. This was applied to an actual site in Korea to find the result and the simulation is verified. The simulation results were compared with the values obtained from the actual site to find similar values for verification. Due to the nature of construction sites, a number of variables occur. Therefore, accuracy was enhanced by applying variables to the simulation for cases where two one-time events occur and to adapt to the occurrence of continuous variables**
**Improvements/Applications: It is expected that this study will serve optimal management for RMC planning in the construction sector. However, many variables can occur at the construction site so the simulation is needed additional research.**

**Keywords: Ready-mixed concrete pouring plan, Simulation, Productivity, Pouring speed, Conveying time**

## 1. Introduction

RMC is a typical repetitive process used in construction projects by producing concrete of quality required by the plant and then transported. According to the growth trends of the RMC industry by year provided by the Korea Ready Mixed Concrete Industry Association, usage of RMC has been constantly growing from 53,392,000 ㎥ in 2010 to 82,224,000 ㎥ as of 2019. This means that concrete placement using RMC is an essential factor for the construction industry. Normal concrete placement processes order RMC and transport it from the batcher plant to the site. At the site, RMC is transported by a pump car and the concrete is supplied through a hopper to begin placement. RMC must continuously perform such process. In the event that RMC fails to arrive at the site on time, unintended cut-offs can occur, which will reduce the quality of the concrete.[1] If the RMC arrives too early, there may be insufficient space at the site, thus having negative impact such as noise, vibration, dust, and traffic congestion in the vicinity. If the standby time prolongs, the RMC pumping time will be exceeded. Such delays and optimal management occur because it is made up of the experience of the on-site manager. This can result in reduced RMC quality and it can result in lower quality of the structure and high impact on construction costs. Therefore, this study aims at predicting the transportation time of RMC and produce and suggest the optimal management plans in a simulation in order to elevate RMC quality management and productivity

This study is on producing a simulation to enhance productivity of RMC and to analyze studies on RMC quality management and productivity. Based on the analyzed data, a general expression for predicting placement time through the amount of concrete on the placement area and the hourly discharge will be deduced to produce the simulation. The time for transportation from the batcher plant to the pump car is analyzed using the general expression. In order to comply with the RMC pumping time, it is presumed that the batcher plant nearest the site is used. There are variables in transportation time such as the surrounding traffic situation and environment, and therefore, average values are used. By presuming the driving speed at the site, the time that it takes for the RMC that departed from the batcher plant to arrive at the site entrance using the distance and time depending on the route, and the time at the standby area, as well as the time from the standby area to the pump car are calculated. The simulation produced through such procedures are given numbers for each RMC to order RMC so that placement is not interrupted. This is applied on the actual site, and the on-site RMC entrance time and placement time are analyzed to verify by comparing with simulation results.

## 2. Materials and Methods

In improving and analyzing construction processes, simulations do not use subjective judgments like the past, but uses quantified and digitized analysis to save on costs and improve the productivity of construction equipment. Despite these advantages, there is little awareness on the expected effects of the simulation, and therefore, simulation activities in the domestic construction industry is very low. Therefore, research on productivity analysis and applicability review for simulations should be continuously made not only for circular and repetitive public works presented in this study, but also for the entire construction process [2]. Studies using simulations were analyzed to enhance construction productivity. A new construction labor productivity model was presented based on actual factors that affect productivity [3]. Simulations were implemented to analyze productivity in steel-frame construction in Korea, and simulations to improve productivity of deck plate floor sheet construction method was used [4] [5]. Also, studies that applied various simulation technologies in construction work such as using the ANN (Artificial Neural Network) and fuzzy model, use of situation-based simulation modeling, etc. for enhancing productivity [6-11].

Korean construction work is operated based on the experience of construction managers, and therefore, it is unable to enhance economic and productivity effects. It is thus necessary to make improvements to the operation method and construction method of construction equipment and operate using a method that can minimize costs of construction equipment in order to enhance efficiency of construction equipment. [12] Korean construction sites usually use multiple construction equipment simultaneously at the site. However, due to the construction method that depends on experience, there are cases in which it does not go as planned, and therefore, it is difficult to order the optimal number of RMC [13].

Many construction sites in Korea depend on experience, therefore resulting in the problem that the optimal number of RMC placement processes cannot be found, thus causing delayed transportation or long wait times, which in turn results in decreased productivity. As simulations for improving construction productivity have been implemented as of late, this study aims at producing simulation based on existing research to predict RMC placement and transportation time for optimal management.

## 3. Modeling to increase the productivity of ready-mixed concrete

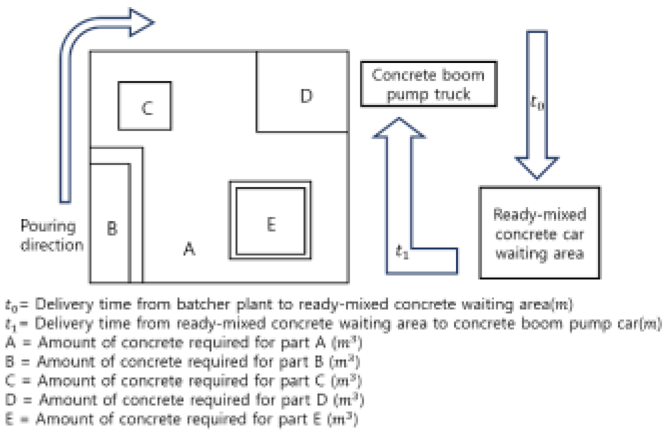


**Figure 1. The movement line from the batcher plant to the ready-mixed concrete car waiting area and the ready-mixed concrete car waiting area to the concrete boom pump truck, and the pouring part and the pouring direction**

Prior to development of the simulation, general cases are presumed and the placement area and placement direction are as shown in Figure 1. Generally, when placing concrete, the placement speed is adjusted considering the difference of lateral pressure and the placement area per part. In Figure 1, the level of changing placement speed by A, B, C, D, E parts was set as unknown and it is expressed in the graph in Figure 2.

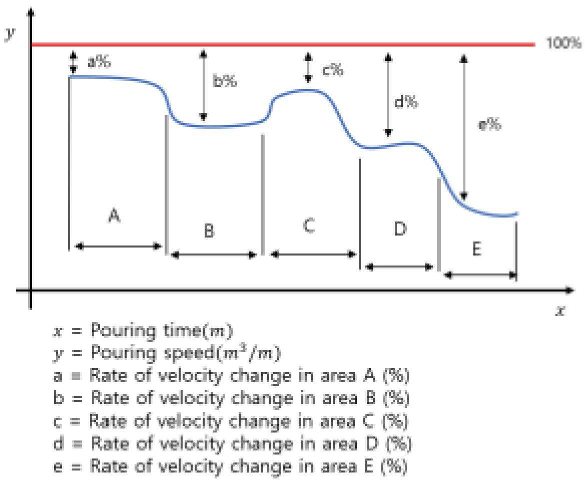


**Figure 2. Graph of change of pouring rate by area**

Placement speed changes by the placement direction and this generates differences in placement time. The time difference is predicted to show the placement time as a general expression. Based on 100%, when placing part $A$, if $a\%$ occurs for changes in the placement speed, in placement area A, placement speed $y$ is multiplied by rate of change $\frac{a}{100}$, and then is divided to find placement speed $x_A$. Then, the next placing part, part B placement is calculated in the same manner, and it is as shown in (1). And then after calculating the placement time for all parts, the placement time can be found. The contents are as shown in (2).

$$A \div \left(y \times \frac{a}{100}\right) = x_A$$
$$B \div \left(y \times \frac{b}{100}\right) = x_B$$
$$C \div \left(y \times \frac{c}{100}\right) = x_C$$
(1)
$$D \div \left(y \times \frac{d}{100}\right) = x_D$$
$$E \div \left(y \times \frac{e}{100}\right) = x_E$$
$$x_A + x_B + x_C + x_D + x_E = x$$
(2)

$y$: placement speed per minute$(m^3/m)$
$x$: total placement time$(m)$
$x_A$: part A placement time$(m)$
$x_B$: part $B$ placement time$(m)$
$x_C$: part $C$ placement time$(m)$
$x_D$: part $D$ placement time$(m)$
$x_E$: part $E$ placement time$(m)$

The placement time can be calculated by predicting the change of the placement speed, and it can respond to parts where placing slows or quickens, and it is possible to predict the time for ordering RMC. The transportation time of RMC is categorized into time from the batcher plant to the site entrance, site entrance to the RMC standby area, and RMC standby area to pump car. Movement from the batcher plant to the site entrance is computed by combining the surrounding traffic situation, distance, and experience. Also, the distance from the site entrance to the standby area, and from the standby area to the pump car route are determined. Then, the distance of the route is measured and after presuming the operation speed of RMC at the site, the time of the route within the site is found. Such data is used to calculate $t0 + t1$ of Figure 1. In the above Figure 1, $t0 + t1$ and $x_A$ are added to make $t_0 + t_1 + x_A$ of Figure 3.

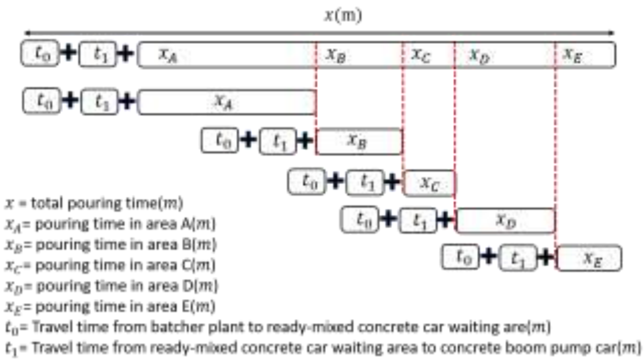


**Figure 3. Simulation model example**

The transportation time $t_0$ from the batcher plant to the RMC standby area, the transportation time $t_1$ from the standby area to pump car, and the part A placement time $x_A$ are added to prepare the RMC so that placement is uninterrupted. The change of placement speed is predicted to order RMC without interrupting placement. Figure 3 shows the placing scope and process, and it was presumed that all A, B, C, D, and E parts are placed within the prescribed time. Placement speed is different for each part and placement speed can change even within the same part. Therefore, multiple RMC performs placing in sequence in the interior as well. It is ideal to have as much RMC as possible to be available in the standby area so that placement is uninterrupted within the site. However, considering the time it takes for RMC to be transported to the site, as well as the standby time, the instance of placement must be within the pumping time. Figure 4 presumes that six RMCs are needed for placement in region A and that there are six units in the RMC standby area within the site, and the pumping time is 90 minutes.

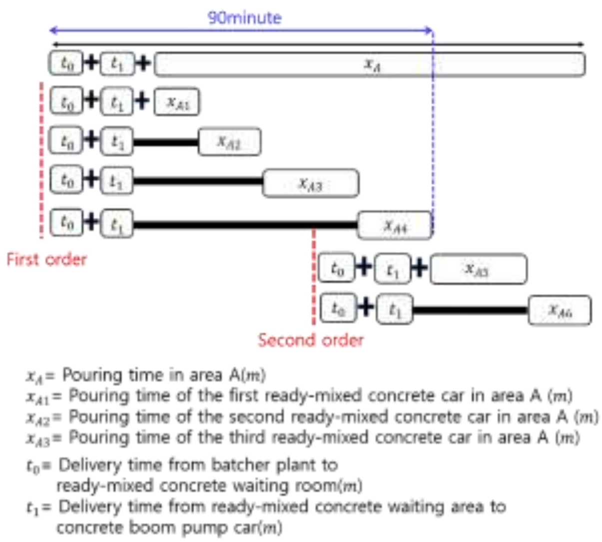


**Figure 4. Simulation model**

Six units can wait at the standby area, but it must wait without exceeding 90 minutes for pump time, and placement must not be interrupted. If six units are ordered at once, when the placement of the fourth RMC ends, the fifth RMC pump time will be exceeded. Therefore, four should be ordered on the first order, and the second order should be made so that the fifth RMC can be placed in the pump car before placement of the fourth RMC ends. $t_0 + t_1 + x_A$ is applied for each RMC to give sequence number for the simulation.

## 4. Simulation

In order to apply the simulation model, comparative analysis is made based on placement information that was conducted at actual sites. The actual RMC shipping time, site arrival time, placement time, pump car specifications, RMC routes and distance, and placement quantity, etc. are used*
This site is an apartment construction site located in Daejeon, Korea, and for the base placement of building 104 ($540m^3$), 90 RMCs ($6m^3$) were used on May 30, 2020. Placement began at 08:53 and ended at 14:45, and the total placement time was five hours and 52 minutes.


**Figure 5. Layout of Construction Site A in Korea**

The pump car location and RMC route at the site is as shown in Figure 6. There is no RMC standby area and it waits in line along the route. The route is wide enough for two RMCs to move in both directions. After placement, it leaves along the route. The length of the one-way route of RMC is about 175m.

■ : Concrete boom pump car

➡ : Ready-mixed concrete car flow

**Figure 6. Concrete boom pump car location, Ready-mixed concrete car flow**

**Table 1: Initial Set of features used for the experimentation**

| | | |
|---|---|---|
| hopper capacity | 600L | |
| pouring speed | lod side | $172m^3/h$ |
| | head side | $115m^3/h$ |
| Pipe size | DN 125/5″ | |
| Water pump | 20 Bar | |
| Water tank | 500 Litter | |

Details of presumptions prior to the simulation are as follows.
1) The time it takes to move from the batcher plant to the site entrance uses the mean value. The actual RMC transportation time is 38.9 minutes on average.
2) The transportation speed of RMC is presumed to be $20km/h$. The distance of the route for RMC is approximately $175m$ and the transportation time is 31.3 seconds, or about 0.5 minutes.
3) The discharge speed of the pump car is based on the direction of the head and it is presumed to be 80% of the max discharge speed. The max discharge speed in the head direction of the pump car as shown in Table 1 is 115, and 80% of the max discharge speed is $92\,m^3/h$. Therefore, the placement time of one RMC ($6m^3$) is approximately 235 seconds, or 3.9 minutes.
4) Pumping time should not exceed 90 minutes. The high temperature in Daejeon, Korea on May 30, 2020 was 29.1℃. According to the concrete standards specifications, the temperature exceeds 25℃, and therefore, the pump time is limited to 90 minutes.
5) RMC at the site waits in the route shown in Figure 7 and up to 13 units can be on standby.
6) The shipping interval of RMC from the batcher plant is

presumed to be one minute.

Simulations are conducted as follows. First, the time used for placing 540 $m^3$ is computed with the general expression detailed above. 540 $m^3$ (placement area)*(1.92 $m^3/m$ (discharge quantity per minute)*80 (discharge speed change) /100)=351.5625 minutes. This is approximately 352 minutes (5 hours 52 minutes). It is similar to the actual placement time of 5 hours and 52 minutes, but this is a theoretical calculation. Therefore, detailed simulations should be conducted based on the calculations to predict problems that affect productivity to respond accordingly.

When computing the time it takes to order one RMC and completing placement, it is 38.9 minutes (batcher plant-site entrance) + 0.5 minutes (site entrance-pump car) + 3.9 minutes (pump car placement) = 43.3 minutes. The first RMC takes 43.3 minutes and as the second RMC waits at the site entrance-pump car route while the first RMC is being placed, 0.5 minutes (site entrance - pump car) + standby time (placement time of previous RMC) is added. When presuming that 13 units are ordered and all 13 are on standby simultaneously, it would be 38.9 minutes + 0.5 minutes + 3.9 minutes * 13 units = 90.1 minutes. The pump time exceeds 90 minutes, so up to 12 units can be on standby at the standby area. As the shipping interval of RMC is one minute, when ordering 12 units, there will be a difference of 12 minutes between the first RMC that arrives and the twelfth RMC that arrives. If 12 are ordered, the pump time is exceeded, and therefore, 12 units cannot wait simultaneously. The placement time of one RMC is 3.9 minutes, and therefore, during the 12 minutes that occur due to the shipping intervals, it is possible to place approximately three units (3.9 minutes * 3 = 11.7 minutes) during the 12 minutes. Therefore, 15 units are ordered simultaneously.

Figure 7 shows the placement process of RMCs 1 to 30 using a graph. The first order is 15 units and 12 units wait in line at the standby area. The time for placement of all 15 unit is 0.5 minutes (site entrance-pump car) + 3.9 minutes (pump car placement) * 15 units = 59 minutes. Also, the time it takes from ordering the RMC to pass the site entrance and get to the pump car is 38.9 minutes (batcher plant-site entrance) + 0.5 minutes (site entrance-pump car) = 39.4 minutes. In other words, by ordering the second when there is 39.4 minutes left for the RMC placement time that was ordered first, placement will not be interrupted. Thus, the second order is made 19.6 minutes (59 minutes - 39.4 minutes) after the first RMC arrives at the site.

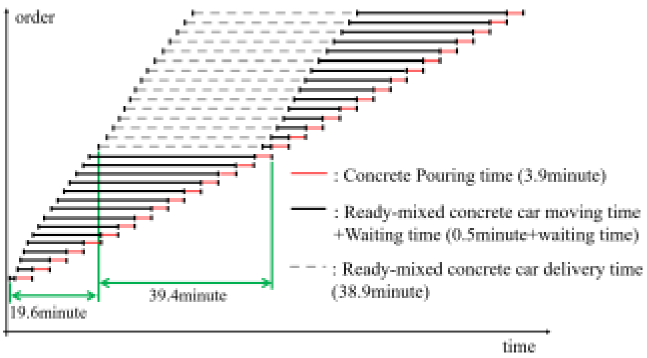


**Figure 7. Second order since first order**

Figure 8 shows the placement process of RMCs number 31 to 60 using a graph. Due to the difference in shipping intervals of RMC mentioned above, in order to have 12 units wait at the standby area, 15 unites must be ordered. Once RMCs number 16, 17, and 18 placements are completed, and while RMC 19 is placing, the final RMC 30 will arrive at the site and get in line to wait in the RMC route. Therefore, the placement time of 15 units is 38.9 minutes + 0.5 minutes + 3.9 minutes * 15 units = 97.9 minutes. However, three units will complete placement while the RMCs are being shipped, and so only 12 units will remain in the standby area, and all placement is possible within the pumping time. From the 97.9 minutes for the placement time of 15 units, the next order is made when 39.4 minutes remain. 97.9 minutes - 39.4 minutes = 58.5 minutes, so the third order is made for 15 units 58.5 minutes after the second order. Orders afterwards should repeat this process to order every 58.5 minutes.

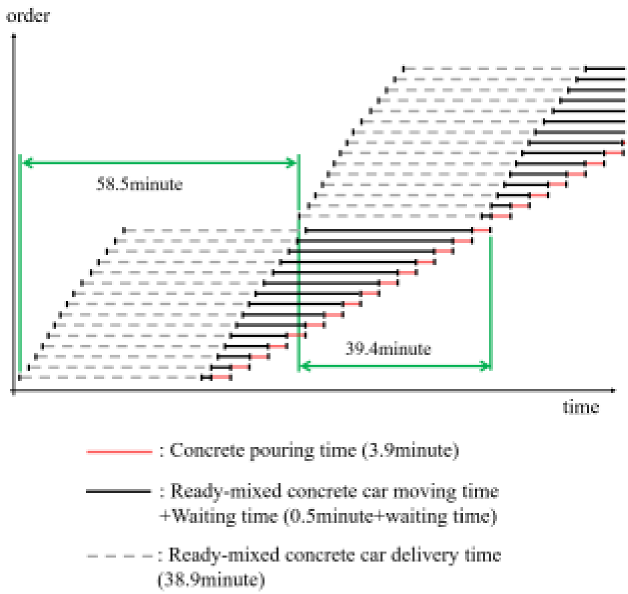


**Figure 8. Third order since Second order**

The limitations of the simulation are clear. It does not take into consideration all of the variables. The simulation conducted is the ideal outcome by applying all presumptions in a constant manner. The actual site cannot be as ideal as the simulation. However, measures should be taken to be as close as to the ideal situation as possible through the simulation.

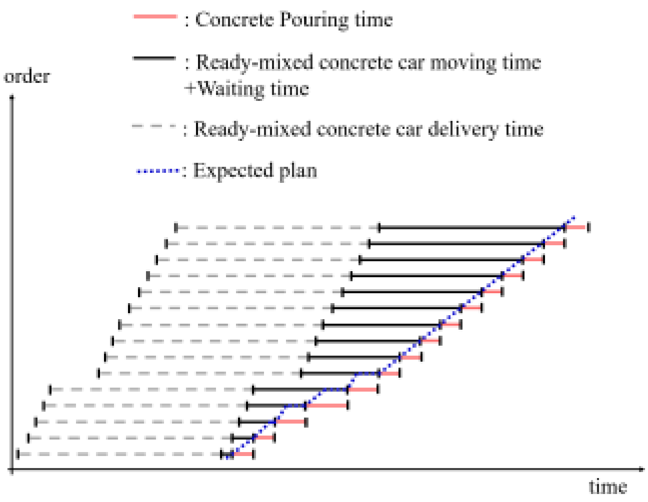


**Figure 9. Expected plan**

Figure 7 and Figure 8 are the most ideal outcomes. Figure 9 shows plans that express the expected placement delay and placement speed changes in the RMC. Because the delay of the placement speed was predicted, orders for RMCs should also be delayed. The graph in Figure 9 mentioned above is a graph planned by predicting changes in the placement speed. The line connecting the time from when the RMC departs will be called the order prediction line here. The order prediction line is needed to respond to variables that occur at site. By connecting all of the planned order times to make the order prediction line, it moves left and right depending on the occurrence of variables. Therefore, it will be possible to approach ideal plans in which placement is not interrupted in response to the occurring variables. There are many variables at real sites. Let's apply two variables to respond to them. First is when one-time incidents occur. One instance is that the RMC does not depart at a constant interval from the batcher plant, and let's assume that multiple units depart simultaneously due to departure delays owing to simple mistakes. It is a simple mistake, and therefore, it is an unpredicted one-time variable. Move part of the order prediction line to the right proportionally to the delay of departure. Reduce the standby time of the RMC so that placement is not interrupted and so that variables do not occur in the next order.

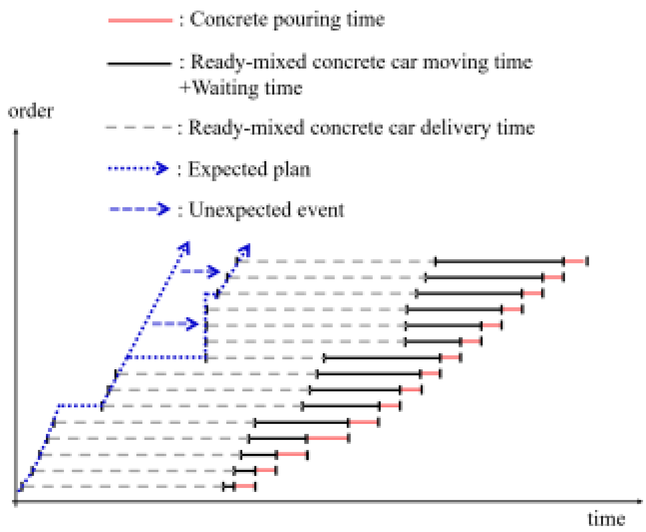


**Figure 10. Unexpected event 1**

Second is a continuous variable. Let's presume that the departure of the RMC from the batcher plant went as planned. But the traffic conditions were poor, and therefore, arrival was delayed. Traffic situations are unpredictable variables. But after becoming aware of this, parts or all of the order prediction line are moved to the left. Delayed arrival of RMC is prevented by ordering in advance.

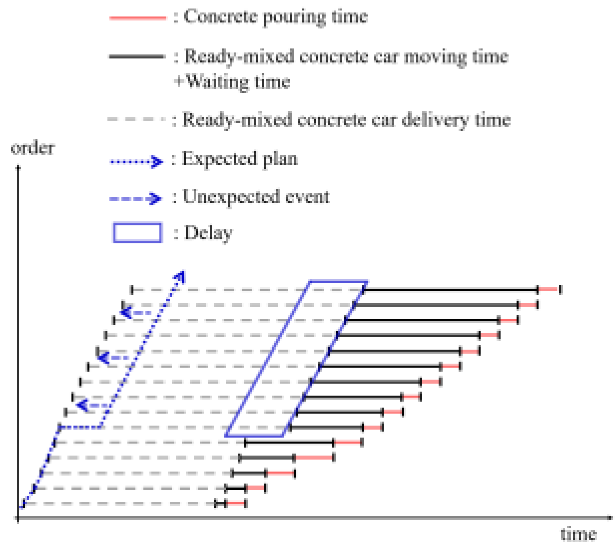


**Figure 11. Unexpected event 2**

## 5. Conclusion

This study produced a general expression and simulation according to the change in concrete placement speed of RMCs and pump cars, which are heavy equipment used in construction sites, to make improvements to the RMC repetition process. Simulations are used to respond to situations that can occur at sites as similar as possible to ideal situations to improve productivity. For this, the site was visited to analyze data such as RMC entry time, routes, etc. Furthermore, the direct general expression was used to compute and predict the placement time. Afterwards, the simulation data values were found to apply in actual construction sites. Through such outcomes, they were divided into predictable areas and unpredictable areas. Predictable parts like change in placement speed were planned in advance to respond by comparing the simulation outcomes for unpredictable variables like traffic situations. Therefore, general expressions and RMC simulations were applied to the construction site according to the change in placement speed to propose improving the productivity of equipment. Though the same work cannot be performed again through the developed simulation, since the actual placement time and transportation time, etc. were reflected in the simulation, the usefulness of this simulation could be indirectly verified.

During concrete placement, there are many cases in which orders of RMCs depend on experience, and therefore, it is difficult to prepare for the ever-changing situations. That is why it is necessary to calculate the expected placement time to simulate, and use data calculated not based on experience. However, because there is no data on general expressions reflecting the change in placement speeds per part at construction sites, there are many limitations in applying it directly to sites. Starting with this study, it is necessary to conduct ongoing research for improving RMC productivity through research on the change of concrete placement speed and collecting and analyzing data.

### 6. Acknowledgment

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