MODELLING AN INVENTORY MANAGEMENT IN CONSTRUCTION OPERATIONS INVOLVING ON-SITE FABRICATION OF RAW MATERIALS

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ABSTRACT

There are usually plenty of material inventories in a construction site. More inventories can meet unexpected demands, and also they may have an economical advantage by avoiding a probable escalation of raw material costs. On the other hand, these inventories also cause negative aspects to increase costs for storing redundant inventory as well as decreasing construction productivity. Therefore, a proper method of deciding an optimal level of material inventories while considering dynamic variations of resources under uncertainty is very crucial for the economical efficiency of construction projects. This research presents a stochastic modelling method for construction operations, particularly targeting a work process involving on-site fabrication of raw materials like iron-rebar process (delivery, cut and assembly, and placement). To develop the model, we apply the concept of factory physics to depict the overall components of a system. Then, an optimal inventory management model is devised to support purchase decisions where users can make timely actions on how much to order and when to buy raw materials. Also, optimal time lag, which minimizes the storage time for pre-assembled materials, is obtained. To verify this method, a real case is applied to elicit an optimal amount of inventory and time lag. It is found that average values as well as variability of inventory level decreased significantly so as to minimize economic costs related to inventory management under uncertain project condition.

KEY WORDS

Optimal inventory management, Inventory cost, Reorder point, Optimal time lag

INTRODUCTION

Material costs constitute more than 40% of the total construction cost, so materials are an important factor for the success of a construction project (Lee, 2004). In general, it is common practice to keep plenty of material inventories in a construction site, because it is too difficult and troublesome to make a small order for construction materials each and every time on demand. These surplus inventories can meet unexpected demands, and also may have economical advantages by avoiding an escalation of raw materials. However, they also have negative aspects; (1) increase financial costs, so-called inventory holding

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costs, and often (2) decrease construction productivity due to excessive storage areas, unnecessary amount of work in process (WIP), and other inefficiencies.

Being aware of these facts, a number of researchers have so far presented an application of lean concepts and techniques for efficient management of certain type of materials (Arbulu et al. 2003, Pheng and Chuan 2001, Tommelein and Li 1999). Those concepts and techniques include value-adding, value stream, waste removal, just-in-time, and *kanban*. Their highest priorities are to attain nearly zero waste and inventory. There also has been research that analyzed the influence of material inventory and experimentally attempted to find out optimal inventory levels (Horman and Thomas 2005, Han et al. 2006, Polat et al. 2007).

Construction projects have many changes and variations through the construction process, so a certain level of material inventory is essential. Moreover, construction firms are increasingly adopting a modularization process involving on-site fabrication of raw materials like the iron-rebar process. This is a more complex system composed of a manufacturing factory of raw material, a temporary assembly shop near the construction site, and a construction site that consumes preassembled products. In this process, there are two kinds of inventories: raw materials delivered from a factory and pre-assembled parts in a temporary shop. To the best of our knowledge, there is no modelling effort that optimizes inventory management for this type of projects. By virtue of all previous efforts, this research aims to present a proper method of deciding an optimal level of material inventories for this emerging process while considering dynamic resource variations under uncertainty from the perspective of site managers.

RESEARCH METHODOLOGY

We conceptualize a construction operation system involving on-site fabrication of raw materials and then identify the essential influencing factors on the system by applying the concept of factory physics. On the basis of system theory, we present an algorithm to investigate an optimal level of raw materials and adequate time lag for storing assembled products. The optimal level of raw material is constructed by the deposition of both statistical inventory model and pulls system. This model is designed to support purchase order decisions on how much and when to order. Also, optimal time lag, which minimizes a storage time for pre-assembled products, queued in an assembly shop, is suggested. To address the uncertain project condition, this research uses Monte Carlo simulation[5] method to obtain an optimal inventory level and to forecast total inventory costs. Finally, this method is applied to the actual rebar fabrication process to demonstrate its effectiveness and validity.

THEORETICAL BACKGROUND

SYSTEM ANALYSIS

System analysis is a structured problem-solving approach with the following characteristics (Hopp and Spearman 2000):

(1) The problem is viewed in the context of interacting subsystems.

(2) The objective always specified first, and then alternatives are sought and evaluated in terms of this objective.

[5] A tool which uses random numbers to measure the effects of uncertainty in a spreadsheet model (Crystal Ball 7.2 user guide)

(3) With the objective in mind, the system approach seeks as broad a range of alternative policies as possible.

(4) To compare alternatives in terms of the objective, the modelling/optimization step is carried out for quantification.

(5) In almost every system, the objectives, alternatives and model are revised repeatedly because real-world systems are complex.

There are four basic phases in system analysis. Based on these four phases, a system analysis procedure of an inventory management system in the domain of this research scope is developed as shown in Table 1. Following these steps, the system analysis of a current operation is performed to broadly understand a work process and to seek any insight for improving a current system.

Table 1: System Analysis Procedure of Inventory Management System
Revised from Hopp and Spearman, 2000)

Phase	Details	Associated Tools and Techniques
Operation Analysis	Setting Objectives/Constraints, Looking for Problems, Modelling, Looking for Control Factors	Investigation/Survey, Business Process Design, Influence Diagram
System Design	Look for Alternatives, Optimize Control Levels	Probabilistic Modelling
Implementatio n	Implement Policies, Performance Analysis	Monte Carlo Simulation
Evaluation	Site Manager Interview, Feedback	Interview/Question

PUSH AND PULL SYSTEM

A push system schedules the release of work based on demand, while a pull system authorizes the release of work based on system status (Hopp and Spearman 2000). This definition means that a push system release materials or a job to the site precisely when called to do so by an exogenous schedule, and the release time is not modified according to what is happening in the site. In contrast, a pull system only allows ordering materials or a job onto the site when a signal is generated by calling for it. In terms of inventory management, however, a pull system can be more effective in that it is easy to meet unexpected changes and allows low inventory into the system. The concept of a pull system is implemented in the modelling feature on the whole in this paper.

STATISTICAL INVENTORY MODEL

In the conventional inventory management model, many factors are assumed to be deterministic: thereby are much different from real situations. When there is a possibility to encounter an arbitrary situation, it should be addressed into the model in terms of probabilistic nature. The model that is widely used in manufacturing industry as a production planning tool is the “reorder point policy”, which classifies issues on inventory control into two parts (Anupindi et al. 2005); (1) the decision on order quantity or inventory quantity that will be either purchased or produced at every time of supplement; and (2) the decision on reorder point or inventory level when a supplement is required.

Figure 1 exhibits an inventory pattern under the conditions of such an inventory model. Inventory is to be observed continuously while demand occurs in an arbitrary fashion. In particular, under a situation where everything happens to come together, if the inventory level reaches the reorder point (ROP), the order quantity (Q) needs to be measured based on the lead time (L) and the slope of inventory utilisation (R). Here, the solution is to determine adequate Q and ROP. Also, in determining Q and ROP, a safety level of inventory (I_s) should be considered to avoid any possible stoppage due to lack of inventory. The model to deal with such issues is called the (Q,r) model (Hopp and Spearman 2000). This model, however, primarily deals with the steady and deterministic nature of inventory management.

In this paper, optimal order quantity and reorder point that minimizes the inventory management cost is to be sought based on a statistical inventory model, and also the optimal inventory level is elicited accordingly.

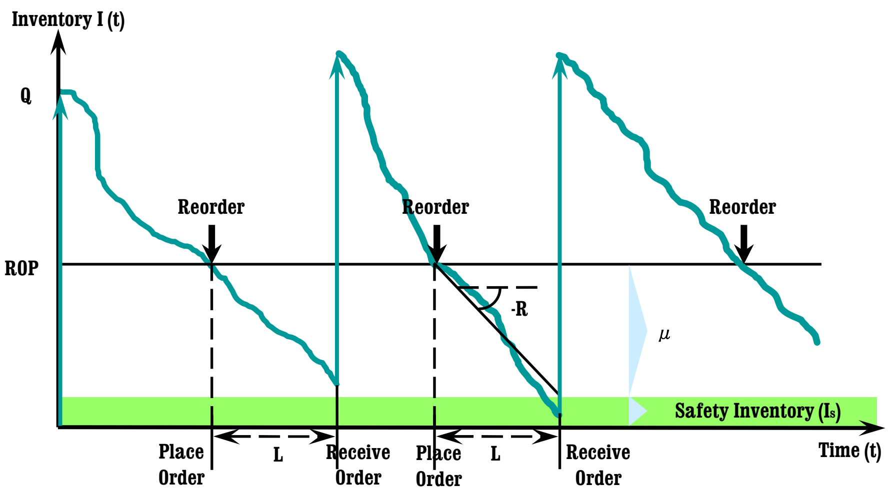

Figure 1: Inventory Pattern in Statistical Inventory Model (Anupindi et al. 2005)

ANALYSIS OF EXISTING SYSTEM (OPERATION ANALYSIS)

In this section, the inventory management system is analyzed in accordance with the procedure of system analysis presented in the previous section. Then, a method to manage the optimal level of inventory is presented. Following the analysis of existing system operations, system design is conducted to draw the valuable insights.

SETTING OBJECTIVES AND CONSTRAINTS

As previously stated, the primary goal of this research is to elicit an optimal inventory level in the process of construction operations, involving fabrication/assembling process for raw materials. This research proposes a strategy in order to control inventory up to the optimal inventory level. In order to maintain an optimal inventory level while considering the entire system, detailed works and their interrelationships should be conceptualized.

In general, jobs relating to materials procurement are divided into two sections: (1) large-scale procurements performed in the head office (centralized purchases), and (2) on-demand procurements related to work progress (jobsite purchases). In this paper, we focus on the works related to the site material management. Particularly, rebar inventory management that requires the fabrication/assembly process for materials within a temporary processing shop near the site is the focus of our study. This type of material processing has steadily increased in large-scale civil and industrial projects because it can satisfy demands from the relevant construction site in a timely and effective manner in the nature of temporary construction operations.

DIAGNOSING PROBLEMS OF THE SYSTEM

Considering the objectives and scope of this analysis, problems on the current system are derived through the established process. The current system involving the processing process for raw materials is composed of flows of materials and information among the manufacturing factory; temporary assembly shop for processing raw materials; and the construction site where processed materials are installed. Through site investigations and field observations, it is found that inventory management on such a process has the following problems:

1) In general, the concept of an optimal inventory is deemed lacking, so inventory management primarily relies on the field manager's experience and intuition. It brings difficulties to the management thereof and causes to disburse unnecessary expenses.

2) There is a lack of tools to predict accurate demands in the locale of uncertain construction sites, so that it produces a difficult situation for a temporary assembly shop to timely respond to variable changes in the demand of the works.

3) Theoretically, it is not necessary to store assembled materials because it is on the "make-to-order (MTO) basis from the construction site. However, the amount of assembled inventory tends to increase by holding additional products that were processed earlier than the schedule of installation on the site.

MODELLING THE SYSTEM

Business Process Design (BPD) is used for modelling as exhibited in Figure 2. The basic input in the model is raw materials produced in the manufacturing factory. As seen in the model, total inventory within the system can be regarded as the sum of the inventory of raw materials, WIP (work in process) in the temporary shop, and assembled products that are queued.

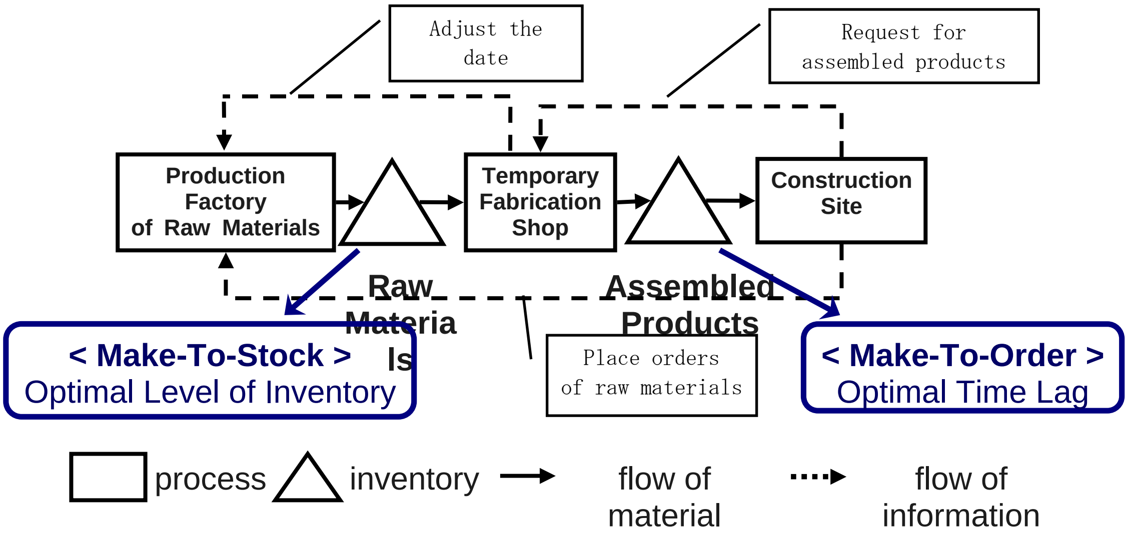

Figure 2: BPD of the Inventory Management System

Raw material inventory occurs when raw materials delivered from the manufacturing factory have been queued by the temporary shop in order to process those raw materials. As works keep going continuously at the temporary shop, raw materials need to be secured up to a certain level in advance. Thus, during delivery of raw materials to the temporary shop, it is required to maintain a safety buffer against the volatile demands on the make-to-stock (MTS) basis so that the optimal level of raw material can be elicited accordingly. Meanwhile, the inventory of assembled products occurs when they are lined up in the temporary shop prior to delivery to the construction site. Assembled products are usually produced after receiving orders from the construction site in accordance with work schedules and shop drawings. Therefore, production of assembled products can be said of being on a make-to-order (MTO) basis. Here, the important thing is to determine when to begin the assembly job at the shop on the basis of site demand. The earlier the assembly work starts, the more the inventory of assembled products. Conversely, the later the work begins, the higher the site can be stopped due to the lack of inventory. Accordingly, it should be required to elicit an optimal time lag for assembling job while minimizing the inventory of assembled products.

IDENTIFYING CONTROL FACTORS

To identify control variables after examining the current system through BPD, the influence diagram on inventory is drawn as shown in Figure 3. It is developed using the Influence Diagram technique.

When examining the Influence Diagram, lead time variance, demand variance, and temporary shop size have direct influence on the inventory of raw materials. Further, demand variance, variance of daily production in the temporary shop, and size of a temporary shop also affects the inventory amount of assembled products. The high level of inventory affects the economic costs that are related to excessive storage and maintenance costs. Productivity also can decline due to interference and overcrowd of construction site. Likely, low inventory levels affect the possible absence of stock provoking work delays. Since the impact of productivity is ultimately incorporated into the economic costs, the authors attempt to measure the whole cost influence associated with inventory level through the use of economic costs.

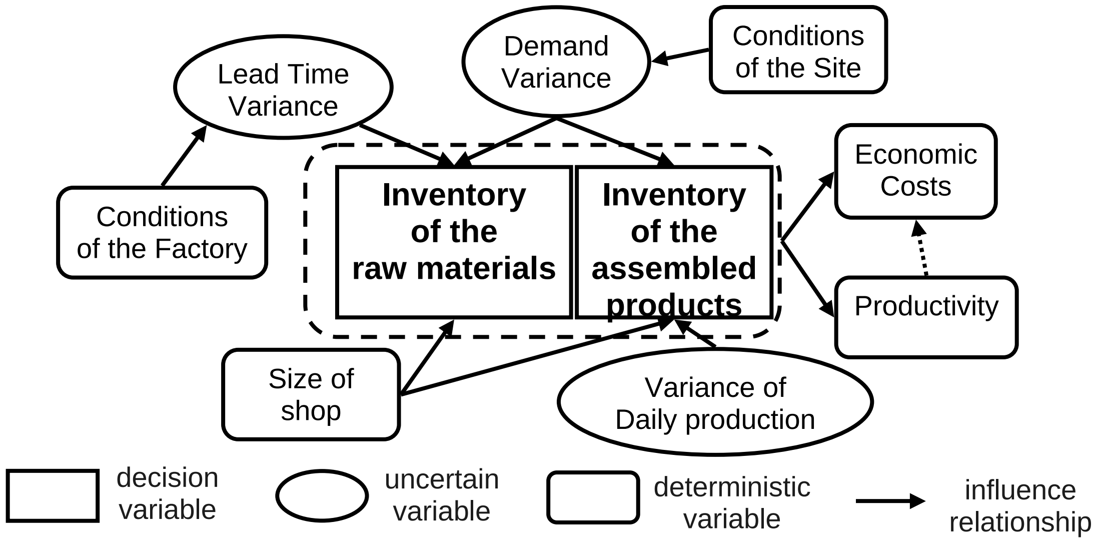

Figure 3: Inventory Influence Diagram

Accordingly, this research presents the optimal level of raw materials and the optimal time lag for assembly jobs, which can minimize the economic costs on the whole. In this process, key control factors such as lead time variance and demand variance are carefully investigated to keep the inventory level as low as possible.

OPTIMAL INVENTORY MANAGEMENT MODEL (SYSTEM DESIGN)

RAW MATERIAL INVENTORY

At first, methods to determine Q and ROP that minimize the economic costs relating to inventory levels of raw materials are presented using Monte Carlo simulation. As for simulation tools, Crystal Ball[6] is used to forecast consequential values under uncertainty based on an Excel spreadsheet model. To perform simulations in Crystal Ball, an Excel spreadsheet model is first constructed, where cells inside the spreadsheet are defined as having one of three attributes, namely, assumption, decision, and forecast. Through the assumption cells, it is possible to include key control variables by giving random distributions to the specified cell. Decision variable refers to the factor that should be decided in the model. By deciding upper and lower limits, decision can be made within such limits. Through assigning forecast attributes, the objective value can be predicted in a probabilistic form according to assumptions and decision variables, employing the objective function to forecast with. The attributes of the model used in this research are shown in Table 2. Input and output information, and framework are also illustrated in Figure 4. Mathematical algorithms embedded in the Excel simulation model for estimating Q, ROP, and total inventory costs are not included here for the sake of brevity.

[6] A graphically oriented forecasting and risk analysis program that takes the uncertainty out of decision-making using Monte Carlo simulation (Crystal Ball 7.2 user guide)

Table 2: Attributes of the Excel Spreadsheet Model (Raw Materials)

Assumptions	Decisions	Forecasts
Lead Time variance, Demand variance	Order Quantity (Q), Reorder Point (ROP)	Total Inventory Cost

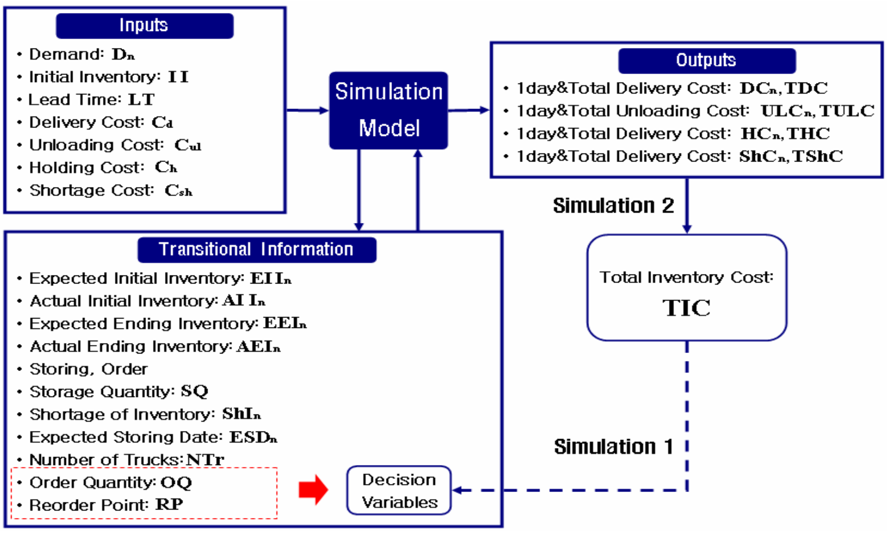

Figure 4: Input and Output Information and Model Framework (Raw Materials)

ASSEMBLED PRODUCTS INVENTORY

In a similar way, in the part of assembled products inventory management, a method to determine the optimal time lag that can minimize economic costs related to the assembled products inventory can be developed using Monte Carlo simulation. The optimal time lag aims to decide whether or not to start the assembly job having time buffer to a certain extent before delivery to the designated construction works. Attributes of the model used to control the assembled products inventory are shown in Table 3. Input and output information, and frame work are organized and shown in Figure 5.

Table 3: Attributes of the Excel Spreadsheet Model (Manufactured Products)

Assumptions	Decisions	Forecasts
Work amount/day, Variance of daily production	Time lag (Start date of assembly job)	Total Inventory Cost

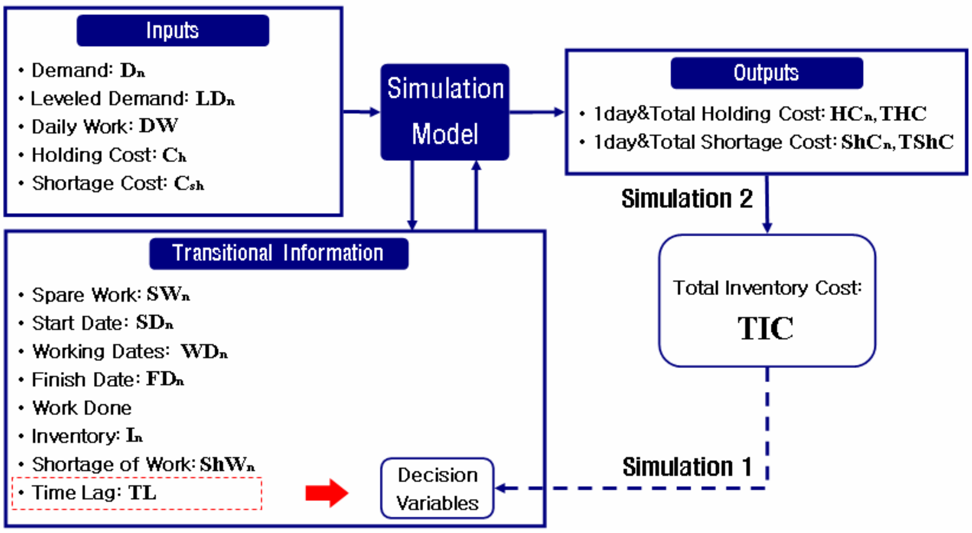

Figure 5: Input and Output Information / Framework (Manufactured Products)

CASE STUDY: IRON-REINFORCED BAR FABRICATION PROCESS

The case project was the inventory management system of the temporaryshop to produce iron-reinforced bars in the light-rail transit construction site around the Seoul metropolitan area in Korea. Construction work was performed in an urban area crossing the heart of the city and commercial district so there was a high likelihood of changes in time schedules due to permits as well as public resistance or complaints on the project. Also, the storage area for material inventory was very limited. The rate of indirect costs of inventory management is relatively higher than that of rural area's. Therefore, it can be noted that this site necessitates efficient management of material inventory. To analyze the actual situation of inventory control, a survey on material flows during the last six months was conducted, primarily based on field reports that informed the daily inflow and outflow of raw materials and assembled products. By applying these actual data to the model proposed, a comparative analysis is performed to draw any advantage over conventional experience-based method.

ASSUMPTIONS OF INVENTORY COSTS

Costs related to material management can vary depending on the construction site and work process. Cost assumptions were set up on the basis of interviews with the field manager who has been working at the temporary assembling shop at the construction site. Inventory costs can be divided into: (1) delivery and maintenance cost of raw materials, and (2) stockout cost when stocks of assembled products are dried out. Delivery and maintenance costs of raw materials are those costs required for delivering, storing and keeping materials at the shop after issuance of purchase orders. Stockout cost refers to the acceleration costs required when stock materials are lacking and additional compression costs are necessary to avoid the delay of construction duration, including such cost as rushing, overtimes, and overhead costs.

OPERATION ANALYSIS

The sample project tended to keep a safety stock large enough to hold a cache of more than one month's worth of raw materials due to the lack of optimal inventory concepts.

They could not even grasp the exact amount of inventory within the premises of the temporary fabrication shop. Also, despite the fact that it is not necessary to keep additional assembled products, it was found that, actually, they were queued for 4 to 7 days, largely due to inconsistencies between production schedules of the temporary shop and actual work schedules at the construction site. Table 6 (As-Is) shows an ineffective arrangement of the amount of inflow and outflow of material per month, measured at the temporary shop.

OPTIMAL RAW MATERIAL INVENTORY

In this part, a simulation was performed having outflow materials as actual demands at the temporary shop. Probability distributions of monthly demands were derived from data fitting based on daily variations of each month by using data gathered through field observations. Procurement lead time was also assumed to have a Poisson distribution because lead time values should be random as well as positive on a monthly basis (integer values). Through the simulation process as depicted in Figure 4, monthly optimal order quantity and reorder point were elicited. Table 4 indicates results of the simulation. As compared to Table 6 (As-Is), March and April values, when work progress rates were not productive, were found to be relatively low while those of May and June were at a higher level having high progress rates. During the rainy season (July and August), order quantities are lower due to the slow work pace, but reorder points are relatively high. That can be explained by the fact that the stock inventory of a previous month (June) was very high so reorder points of July and August were also elicited as high to reflect the circumstances of the previous month.

Table 4: Monthly Optimal Order Quantity and Reorder Point (unit: ton)

Month	March	April	May	June	July	August
Order Quantity (Q)	70	65	95	105	50	55
Reorder Point (ROP)	145	230	395	370	320	350

OPTIMAL ASSEMBLED MATERIAL INVENTORY

In another part of the assembled products inventory, the optimal time lag was elicited using the method as presented in Figure 5. Also, the total inventory cost was forecasted by applying those values. Table 5 is an arrangement of the simulation results of monthly optimal time lags. Similar to results of Table 4, it was found that time lags (lag between actual delivery time to the work site and pre-assembling time at the factory shop) were the highest during May and June when the progress rates were most productive. These time lags aim to shield against the variable demands of the job site.

Table 5: Monthly Optimal Time Lag (unit: day)

Month	March	April	May	June	July	August
Time lags	2	4	5	5	4	4

ANALYSIS OF PERFORMANCE

Results from the application of the model (to-be) is compared to the as-is state. Figure 6 shows the flow of inventory quantity before and after the application of the optimal inventory management method. Table 6 also shows the monthly inflow and outflow of materials as well as average inventory quantity. As seen in Figure 6, the flow of inventory is levelled to display a narrow range of variation comparing to the as-is state. The proposed model can keep the stability of inventory at levels below 500 tons. Also, Table 6 explains that the monthly average amount of inflow material can be kept at an optimal inventory level in association with the amount of outflow of each month (demands). The primary benefits of this model are not only the reduction of average inventory amounts, but also the flatness of standard deviations. It implies that the inventory quantity in the construction site can be reduced in a more stable fashion. Accordingly, inventory management costs of the temporary shop has been decreased by a level of 25% comparing to the as-is state. Even though, this is the result obtained by the simulated situation, it can be the fruit that distinctly shows the effect of decreased inventory management costs, being achieved through means of applying the optimal inventory management strategy.

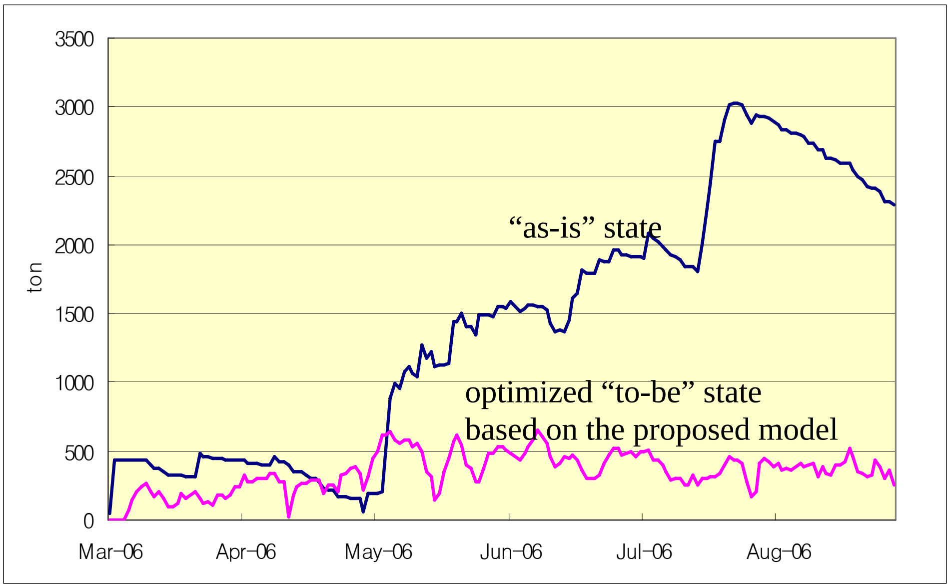

Figure 6: Flow of Inventory Quantity before and after Application

Table 6: States of Material Inventory (As-Is & To-Be) (unit: ton)

Month	Average Inflow (Receiving)		Average Outflow (Releasing)		Average Inventory		Standard Deviation (daily variations)	
	As-is	To-be	As-is	To-be	As-is	To-be	As-is	To-be
March	571.7	350	178.2	178.2	329.0	134.8	89.3	77.1
April	76.1	455	353.1	353.1	302.1	257.1	94.0	68.7
May	2,278.6	1,140	962.2	962.2	922.8	437.1	500.0	140.0

June	1,131.0	630	659.0	658.9	1,619.0	464.3	177.7	86.6
July	1,499.8	400	519.0	518.9	2,225.8	367.8	474.2	96.8
Aug.	53.1	715	707.0	707.0	2,589.6	382.5	199.5	53.9
Total	5,610.3	3,690	3,378.3	3,378.3	1,410.6	348.5	937.6	140.8

CONCLUSIONS

This paper developed a probabilistic optimal inventory management model on the process of construction works that involves on-site fabrication of raw materials like the iron-rebar process. It is a unique system composed of a manufacturing factory of raw material, a fabrication or assembly shop, and a construction site. This process is characterised by distinctive inventory flows. To reduce inventory quantity and costs, it is required to maintain an optimal level of raw materials at the temporary shop. More to the storage of raw materials, the inventory of assembled products occurs when they are lined up in the temporary shop prior to delivery to the construction site. Accordingly, it should be required to elicit an optimal time lag for the start of assembly jobs that can minimize the inventory of assembled products.

The proposed model was applied to an actual case to verify its performance and advantages. Without a systemized tool, the current inventory flow was ineffective with the irregular patterns by displaying unnecessary large quantities of raw materials as well as higher levels of time lag buffers. This inefficiency was significantly improved by the proposed model. Results from the case application are summarized as follows; (1) By applying the pull system to the phase of raw material inventory management, the amount of inflow and outflow iron-bars at the temporary shop achieved a balance, and accordingly, average inventory quantity and inventory management costs were also evidently reduced, and (2) By eliciting optimal time lags relating to the start of fabrication/assembly works, it was possible to reduce the holding time of assembled products, and accordingly, inventory management costs could be reduced around a total of 25%.

However, there were many assumptive views in relation to such cost factors as inventory storage cost, delivery cost, and additional costs when the materials are exhausted. It is recommended to conduct future research to quantify those cost aspects under different project conditions in a more realistic way. Moreover, such areas to reduce the level of variance of influential factors that affect the level of inventory will be central parts of our future research.

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