Resource-based Multi Method Simulation Model for Super-Tall Building Construction

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ABSTRACT

Construction material supply on schedule is an indispensable factor for task operation and accomplishment of successful construction project. Material flow in construction project, horizontal and vertical move and stand-by in the temporary storage, is able to occur the impact on the construction schedule. However, despite the material flow consists of various tasks using plenty of construction resources (e.g. space, time, labor and equipment), the tasks concerning material flow have been excluded from management domain of scheduling methods. In a super-tall building construction project whose shape is vertically long and whose site is usually located at a congested urban area, the limited material storage space and insufficient hoisting equipment are applied as critical constraints on material delivery on schedule. The characteristics of super-tall building construction such as multi-task operation, non-repetitive operation resulted from irregular building shape, and the interaction between schedule progress and material flow make it hard to identify the behavior pattern of material flow and to make an appropriate plan. These uncertainties remain as a critical risk and occur a schedule delay. This study aims to propose multi-method simulation model incorporating discrete event method and agent-based method in order to understand the complexity of material flow under the various constraints in super-tall building project and also to propose optimizing model on ordering amount and time to prevent construction delay.

INTRODUCTION

Construction resources such as labor, material, and equipment can be considered as an indispensable factor to materialize all of the construction activity and it is important to supply these resources to the activity location as many as necessary within the time (Akintoye 1995). Also, a large portion of activities in construction site is assigned to move and store the construction resource using many types of resources as shown in Figure 1. However, these tasks concerning the material flow are generally excluded in the schedule management domain by the construction manager because the impact on construction project duration is not critical in a general construction schedule where sufficient construction equipment and space is secured (Akintoye 1995; Kini 1999).

However, in a super-tall building construction project, which has a vertically tall shape, the material flow is liable to be disturbed and it can critically impact the construction schedule. This type of building is characterized by two features in terms of material management: (1) a large amount of material and labor should be moved especially vertically; (2) tense schedule makes all task type of construction activities to be simultaneously operated and a large amount of material should be handled at once. In addition to these characteristics, this construction project involves three constraints resulted due to building shape and scale: (1) insufficient number of hoisting equipment due to small installation space; (2) limited space for temporal material storing for both outside and inside the building; and (3) tight construction schedule whose delay leads to large sums of cost loss.

Although the failure of resource supply has a large impact on project success, there are several difficulties analyzing the material flow and its impact under the space and equipment constraint. (1) Material flow and utilizing equipment is different by material type since their physical and chemical property are different and requires specific treatment for transporting, hoisting and storing. (2) The way that space and equipment constraint affect the material flow is different by the material type and by the step of material flow even for the same material type. (3) The relation between construction task and required material consist from many-to-many relationship. (4) Irregularity of building shape makes project schedule non-iterative. (5) The interaction between material flow and schedule progress is the cause of the complexity by generating the irregularity in the material flow.

Many previous researches have made an effort to analyze the relation of resource and schedule such as resource leveling and allocation (Hegazy 1999; El-Rayes and Jun 2009; Damci et al. 2013). However, despite the contribution of these researches, they are not adequate to figure out how space and equipment constraint influence the material flow or how much resource in the construction site affects the construction schedule.

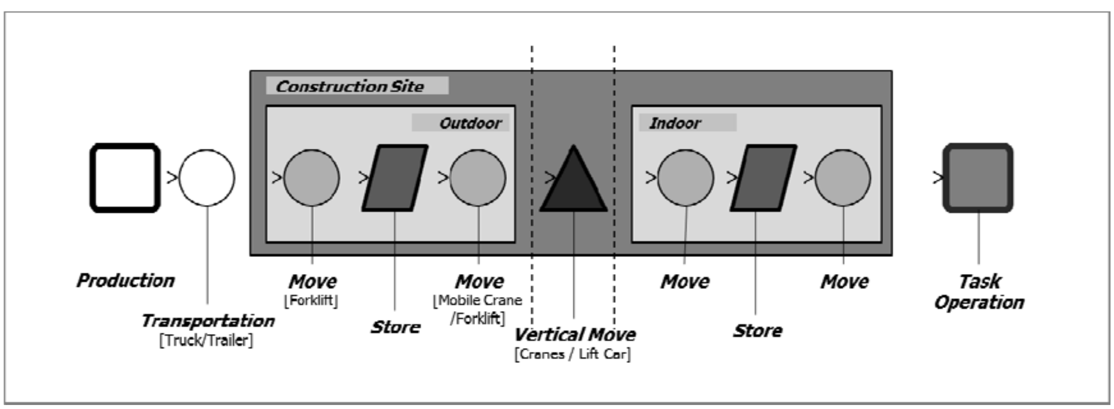

Figure 1. Construction material flow and equipment

This study aims (1) to understand the complexity caused by the interaction among components of the material flow and the assignment of insufficient space and equipment resource, and (2) to develop the multi-method simulation model using discrete event simulation and agent-based simulation, which can explain the complexity of the material flow in a construction site in order to examine the relation between the amount of construction material order and the project schedule delay. For the development of the simulation model, ten representative construction materials for five work types (core-wall, structure, curtain-wall, finish, and MEP) are selected through the construction expert interviews.

METHODOLOGY

The multi-method simulation model incorporating discrete event method and agent-based method is utilized to explain the complexity of fluctuating material flow affected by the space and equipment constraint, schedule progress, and construction manager's anomalous control and management.

Discrete event method. Discrete event simulation model composes events defined by discrete time and sequence and it is known as a valuable tool for the quantitative analysis of construction schedule and operation(Shahin et al. 2011) because of it efficiency not to simulate each moment of time while continuous simulation does. Many researcher have used this method and made an effort to model the construction project scheduling and task operation(Halpin 1977; Kavanagh 1985; McCahill and Bernold 1993; Chehayeb and AbouRizk 1998) and material logistics (Kang and Mirando 2008; Cho et al. 2013) in a construction site. Despite the advantages of discrete event method, there is a limitation due to continuous variation implied in the construction project.

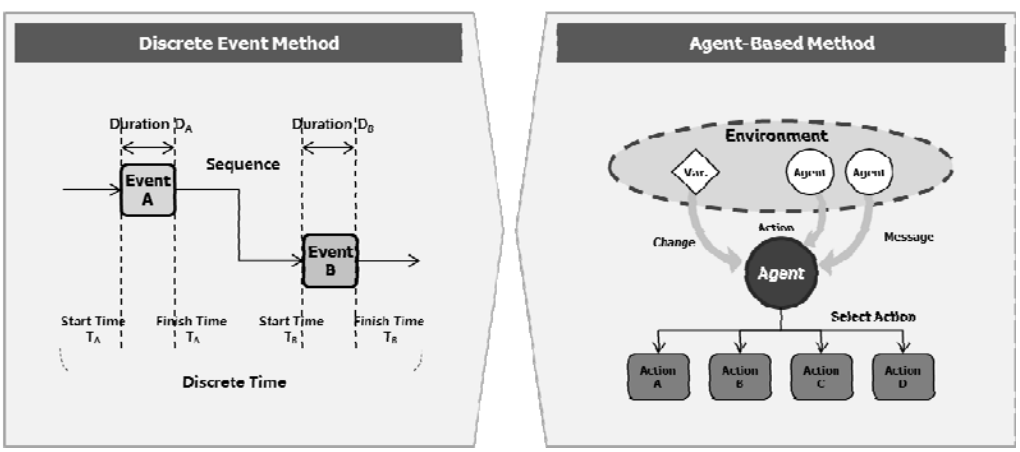

Figure 2. Discrete event method and agent-based method

Agent-based method. There is no consensus definition about agent-based method, it may interact with one another or the environment in continuous time and autonomously make a decision without the direct control of other systems (Bellifemine et at. 2007). Simulation model of this technique is suitable to analyze the variation of construction project schedule and material flow.

Schedule proceeding interacts with the material flow of both inside and outside of construction site. Material supply delay causes schedule proceeding and schedule delay may also change the material flow. This fluctuating material flow is actually controlled by a construction manager who observes the environmental variation and makes a decision on schedule process. Limited material storing space and hoisting equipment cause the competitive situation concerning the assignment of scarce resource. Material without resource assigned on schedule brings about the variation of schedule proceeding and it conversely adjust the resource assignment plan. In this feedback process, the behavior of the construction material flow becomes complex and it makes hard to recognize the pattern of the behavior.

This study incorporates discrete event and agent-based simulation method in order to describe the complexity of construction material flow. Figure 2 illustrates the different operational mechanism between discrete event method and agent based method.

MODEL DEVELOPMENT

Simulation model description. The purpose of this model is to analysis the relation among material procurement, order amount and period, and schedule delay under the space and equipment constraints of the construction site. In order to represent this complex system, the simulation model consists of three parts: construction schedule model, material logistic model, and material flow control model. As shown in Figure 3, material flow model explains the material logistics from production in factory to utilization at the working space by representing the material physical properties, the storage size and location, hoisting equipment ability and capacity, and the distance of movement. Schedule model, which expresses the construction activities and sequence operated by the material arrival from material logistic model. Material flow control model represents the behavior of the construction manager who controls the material procurement and inventory level in a construction site by considering the storing capacity and the material consumption rate. These three components of the simulation model create the complexity by interacting with each other.

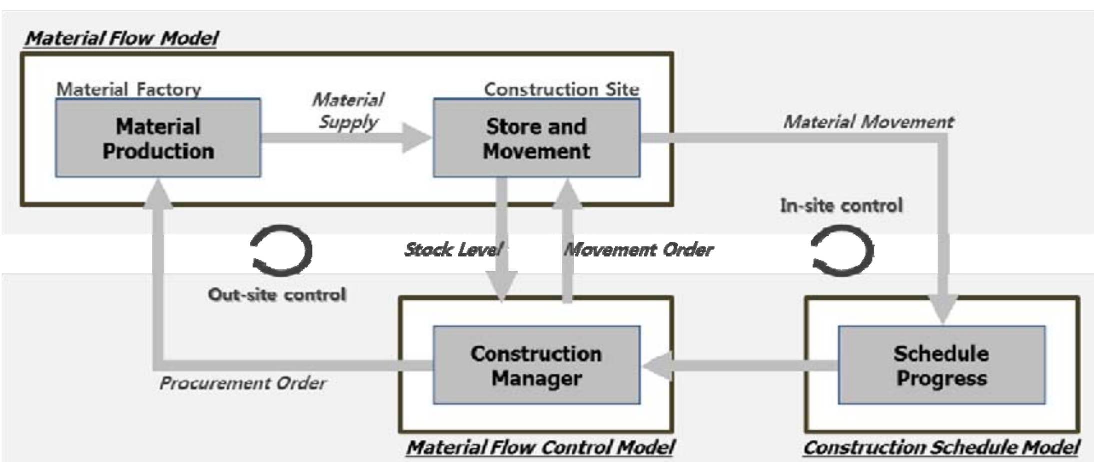

Figure 3. Conceptual model and the interaction among components

Construction schedule model. This model is designed in order to represent the characteristics of super-tall building's construction schedule, irregular schedule process and different material amount story by story due to the irregular shape of the building and structure for each transformed floor. Construction activity represents the above-mentioned five activity types, where each activity is composed of several tasks that begins when the specific type and amount of materials arrives. The same type of activity has the same tasks, while the material amount for an activity can differ even though it is the same type.

Material logistic model. Construction material logistic is modeled using the discrete event method. This model simulates time delay and queue in the material flow from material production in factory to material consumption during task operation as shown in Figure 4. Each event of model is defined as a task concerning the material moving and storing, and the task and process are. Entity representing material contains the information on the material type and destination, shape of the material and package unit, and hoisting type. Considering the information included in entity, the model determines the storing space and hoisting equipment type.

Material production methods applied in this model are make-to-order(MTO) and make-to-stock(MTS). Delay time from procurement order to material arrival at a construction site depends on the material production method and transportation time.

Material movement in a construction site can be classified into two directions: horizontal and vertical movement. Even though both movements utilize equipment, the equipment plan for horizontal move can be adjusted during the construction phase, resulting in a relatively small impact on schedule delay due to equipment shortage or conflict that can be neglected in the model. On the other hand, the equipment for vertical move, such as tower-crane and lift-car, is difficult to alter once construction begins. Furthermore, shortage or stoppage of hoisting equipment can cause a heavy impact on the material flow. In this model, delay time for horizontal move is calculated using the distance and movement speed of equipment without the consideration of the equipment shortage. The equipment operation mechanism for vertical move was modeled by referencing to the previous researches.

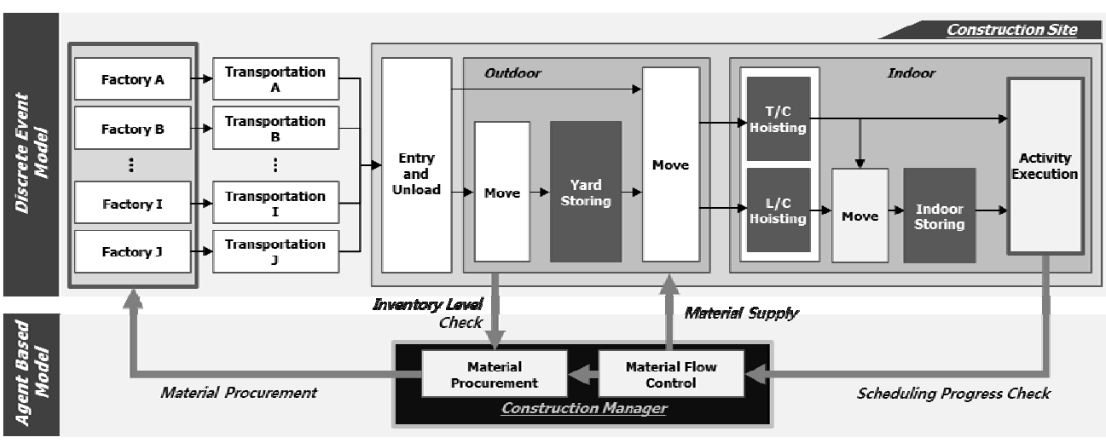

Figure 4. Simulation process of DE and AB model

Material storage is located at the link between movements in the model and the storage capacity and the state of material inventory level influences material flow. This study assumes that abundance of material shape types make it easy to fill the space without any empty space. Thus, the storage capacity and material inventory level are quantified by arithmetically calculating the area of storage space and the sum of area of material package unit.

Material flow control model. In the material logistic model developed in the discrete event method, the process is unchangeable and sequentially progresses among the fixed events. However, in a construction project, actual logistic process can be changed by the construction manager's decision considering the schedule progress or the storage state of a construction site. Material flow control model developed in the agent-based method continuously recognizes the variation of the state in the construction schedule and inventory level and controls the material logistic and flow.

The control domains of agent-based model are in-site control and out-site control(see Figure 4). In-site control handles the material flow if material should be moved or wait in storage. Various types of materials stored outdoors are delivered to indoor storage or task space using hoisting equipment when indoor space is ready to store materials and execute construction task. The procedure which material should be moved to use the limited hoisting equipment is controlled by the agent model. Out-site control represents material procurement, and the construction manager modeled as a single agent model can determine the ordering amount and period reflecting the schedule progress and inventory level of the construction site for each material. Figure 5 illustrates material ordering method using just-in-time system.

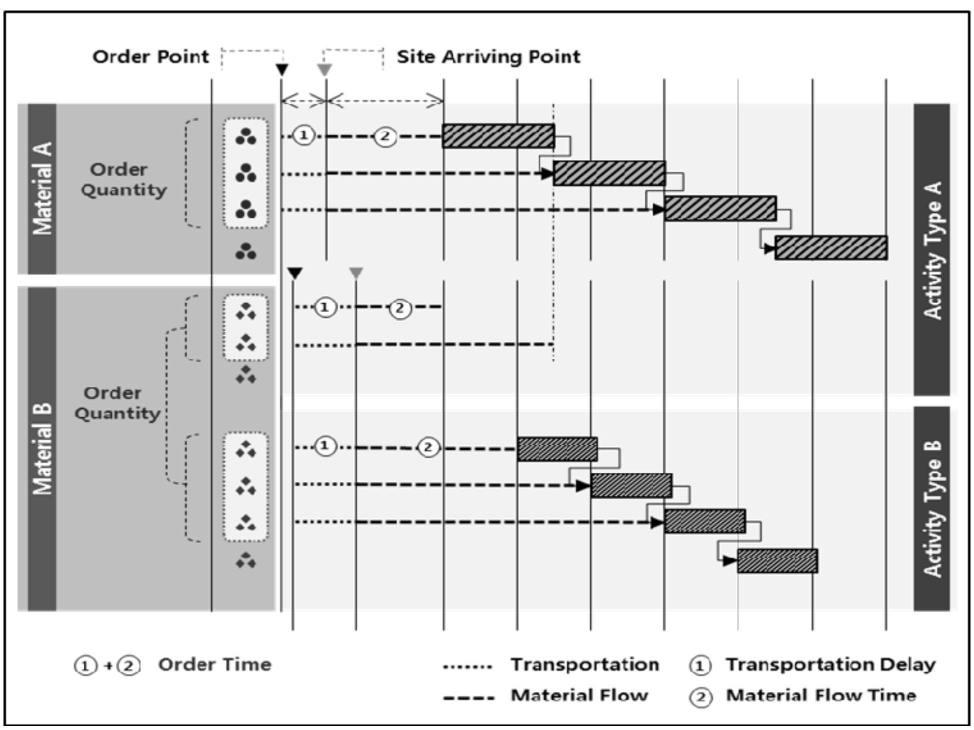

Figure 5. The amount and period of material order

TESTS AND RESULTS

The application case is an office building construction project located in Seoul, Korea. This construction project had operated from July 2009 to April 2012. The project consisted of one building with fifty stories and one conference center with four stories. The influence of material flow by the construction of the conference center, however, is excluded in this application.

The simulation model for this test is developed using Anylogic(ver. 6.9.0 university). The test is designed to analyze the impact of material order period on schedule delay, average inventory level, and average hoisting time per day(tower-crane and lift-car). The duration of each activity and task is set as a deterministic value from planned schedule and the amount of material per order is determined by the amount each task requires. Order period for all material type is set as the same value and the impact of order amount variation by material type is not analyzed in this test.

Table 1. Sample Test and Result

Material Order Time	0	12	24	36	48	60
Avg. time outside of site	18.2	16.5	17.5	19.2	23.3	26.6
Avg. time inside of site	5.6	5.5	12.8	20.4	46.8	96.2
Schedule Delay	3611.6	1531.7	921.6	347.2	2137.2	7322.6
Avg. Inventory level (%)	1.6	2.7	18.6	32.6	64.5	75.5
Avg. Daily hoisting time (T/C)	7.2	7.6	7.5	9.2	10.4	10.6
Avg. Daily hoisting time (L/C)	5.4	5.7	8.2	9.7	10.8	11.2

(Unit: hour)

Table 1 shows the results of the simulation implementation. Material order time means how much time before each task begins where the material is ordered, 36 hours shows the smallest schedule delay time by material supply in this test. The increase of material order time can be considered to increase the inventory level in a construction site and actual delivery time outside and inside of site rises due to insufficient storage space and/or waiting time for the hoisting equipment. On the contrast, too short material order time imputes most of the delivery time to schedule delay even if no shortage of space and hoisting equipment occurs.

CONCLUSIONS AND LIMITATION

This study proposes a multi-method simulation model using discrete event method and agent-based method in order to analyze material flow in a super-tall building construction project under the resource constraint. In a super-tall building project where several types of tasks are operated simultaneously and material storage space and hoisting equipment are insufficient, the complexity exists resulting from the competition of the construction material to occupy the limited storage space and equipment. Also, schedule progress and construction managers' autonomous control makes the system complex by interacting with the material flow. The proposed simulation model is helpful to understand the complexity of material flow and schedule management in the construction site, which is affected by the limited storage space and hoisting equipment.

The study, however, has some limitation caused by arithmetically analyzing the impact of space and equipment constraint without the shape of material and material package. Hence, limitations exist on (1) quantifying the constraint accurately and (2) identifying the confliction between work space and material storing space. Therefore, future work should consider the 3-D shape information of material and space of components by incorporating BIM into the simulation model.

ACKNOWLEDGEMENT

This research was supported by a grant (13CHUD-B059157-05) from Super-Tall Building R&D Project funded by the Ministry of Land, Infrastructure and Transport of the Korean government.

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