A STUDY ON SPACE ZONING BY COMPUTING IDLE-TIMES IN CONSTRUCTION PROCESSES

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ABSTRACT: An inappropriate space zoning plan causes the unnecessary transportation of construction material and equipment among work areas and increases the disorder of work space. Space zoning is an essential operation management technique which contributes to reduce the process and/or operation idle-time. This paper introduces a method that computes the idle-times between construction operations (or processes) by using Web-CYCLONE. It allows computing with idle-times that affect the construction productivity. Using the idle time between operations and between processes, it computes the optimal number of zones and finds the optimal combination of zones that minimize the idle times. The method contributes to minimize the idle times relative to the operation schedule using complete enumeration. This paper presents the system prototype in detail. A case study is presented to demonstrate the system and verifies the validity of the model. It allows a project manager to establish space zoning plan that effectively segregates a project into optimal number of construction zones and to assign the constrained resources (e.g., laborer, equipment).

Keywords: Operation instances, Idle-time, Space Zoning, Micro-CYCLONE

1. INTRODUCTION

Condominium construction in which same processes are repeated requires an operation plan that ensures continuous employment of crews. Space zoning, which is planned at the operation planning stage, is a method to establish and manage operation plans by grouping work zones. It is important for efficient use of limited resources (equipments, materials, labors, work spaces, etc.). The concept of space zoning is to reduce total cost and duration in construction stage by leveling limited resources and managing labors and materials. In other words, inappropriate space zoning plan can cause unnecessary transportation of equipments and materials increases the temporary congestion of work space, suspends work sequence, and dismiss work crews from job-site temporally; therefore, it is necessary to minimize interference among different work tasks by establishing an appropriate space zoning plan.

Discrete Event Simulation (here after DES) has been used to model and analyze construction operations which have repetitive characteristics by using tasks as a basic building block. Construction management has 6-level hierarchy. There are no repetitive characteristics above activity level. However, the construction operations or processes tend to be repeated in the lower levels. It is well accepted that DES is an effective method to optimize a condominium structure construction plan because the operation has repetitive characteristics. CYCLONE, a type of DES, is a useful tool which provides quantitative analysis by creating and measuring construction operation models on a computer [1]. After a construction zone is subdivided into several work zones, a crew is in charge of certain work zones. This causes not only the idle-time between process instances, but also the moving time of the crew from one work zone to another. Therefore, it is possible to provide objective indicators for planning space zoning by analyzing idle-time at the operation and process level, among the 6 levels in construction hierarchy where the repetitive characteristics of the construction process appear. In this study, a space zoning model is built at the operation level, and the standard operation of RC structure construction is modeled focusing on a set of crews. In other words, multiple work tasks handled by each crew are modeled as one process, and a certain crew is involved in a standard operation. The crews are assigned to one construction zone each to perform the processes of multiple work zones in order. The work zones composing a construction zone were assumed to have the same floor plan. In that way, the runtime of the same process is regarded as to follow the regular probability distribution function in all work zones. To analyze the situation, a Web-Cyclone operation model on the critical path of the structure construction is built, and a strategy, which minimizes the delayed-time, occurred on the critical path, is offered by calculating the idle-times. On top of that, it aims to provide objective indicators for decision-making of space zoning by finding the space zoning combination with the minimum idle-time.

2. LITERATURE SURVEY

Since high-rise condominium construction began in the 1990s, the importance of space zoning is highlighted and the studies relative to the subject were conducted. After Glenn Ballard [2] introduced the space zoning and work flow for implementing lean construction, Jurgen Sauer [3] suggested a multi-site scheduling method in which it divides the scheduling zone by 4 categories (e.g., Global predictive, Global reactive, Local predictive, and Local reactive) to fit for each zone's characteristic; Hyun Jeong choo [4] developed the space scheduling system through the correlation of the work and resource flow analysis; Rong-yau [5] suggested the space zoning plan that classifies the gang formwork reuse plan into 5 categories using simulations. There are other studies that were identified the factors which generate the 'idle-time'; however, there is no study to apply space zoning plans by formulating quantitative calculation.

3. METHODOLOGY

3.1 Definition of Idle-time

Grouping multiple work zones as a construction zone causes (1) operation idle-time and (2) process idle-time as presented in Figure 1. Operation idle-time refers to a certain crew's waiting time between the time in which the crew complete a set of work zones and the time in which another successive set of work zones start as shown in Figure 1. On the other hand, the process idle-time refers to the time gap between a proceeding process and a succeeding process in a work zone. It is caused by the unavailability of the crew in charge of the succeeding process in a work zone. Since the crew is engaged in proceeding work zone, it is not available in the succeeding work zone. The process idle-time refers to the delayed-time due to the unavailability of the crew for successive processes.

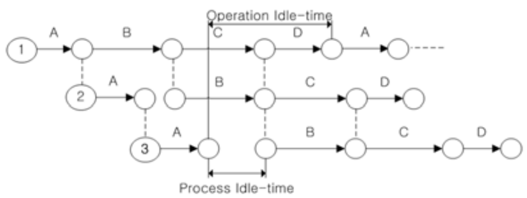

Figure 1. Process and Operation Idle-time

3.2 Primary processes of structure construction

This study mainly focuses on the standard process on the critical path of structure construction that has major effect on project time and costs. The effective operation management is implemented by calculating the operation and process idle-times on the critical path which are the main cause of the project delay. Figure 2 shows a standard operation network of a structure construction. The critical path is progressed in the order as follows; Curing; wall form dismantlement; wall form installation; slab form installation; slab rebar installation; inspection; concrete pouring. Four resources (e.g., carpenters, steel workers, supervisors, and concrete workers) are involved in the process.

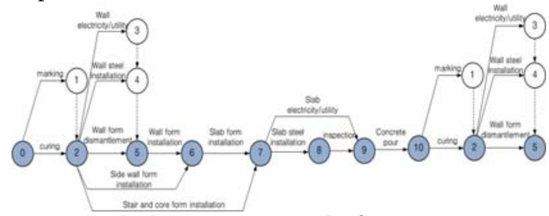

Figure 2. Standard Operation network of structure construction

Figure 3 shows a standard operation network when two work zones are grouped into one construction zone. In a reality of construction job-site, the processes are conducted as one construction zone; in other words, the certain crews conduct different processes simultaneously at each work zone as shown in Figure 3. As a result, this produces the operation idle-time and/or the process idle-time as presented in Figure 1.

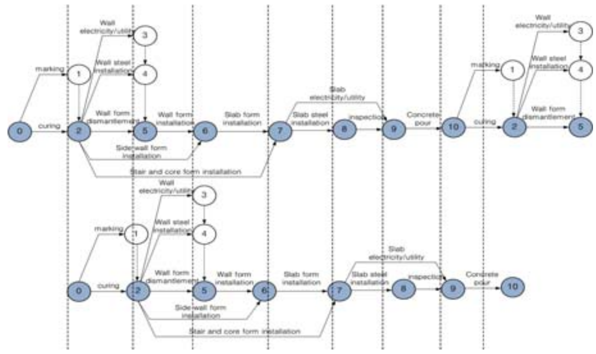

Figure 3. Standard Operation network(2 working zone)

3.3 CYCLONE network model

Based on the scope and hypothesis discussed in previous section, a cyclone network model that groups 3 work zones into one construction zone was developed as shown in Figure 4. Crews perform processes for the construction zone divided into 3 work zones according to the process order.

This model estimates the two types of idle-times (process and operation idle-times) in the primary structure construction by using the number of work zones in a construction project and the numbers of stories of the condominium as the primary input parameters. On the critical path of the structure construction, the 7 serial processes are modeled as one cycle. They include COMBI 7, 10, 12, 15, 18, 21 and 46. The existing cyclone modeling building blocks (COMBI QUE) were logically combined to develop a logic module called BG module (Block Grouping module). The module facilitates to model the crew's movement from the current proceeding work zone in which they are engaged to the next succeeding work zone when the crew finish the process in the proceeding work zone. The module is integrated into the CYCLONE system. To model space zoning processes, the BG module control a signal by capturing and releasing the resource entity. QUE 1 and 2 are the location I which the resource entities were initialized for space zoning. The number of resources is corresponding to the number of work zones that composes of the construction zone. In addition, the number of stories in each work zone is indicated by using QUE 4. The number of cycles of a CYCLONE network model is calculated by inputting the total number of stories of a work zone. The node 4 which receives last signal and removes the signal captured using 'SINC' function. This several work zones will be grouped as a one construction zone using Web-CYCLONE space zoning module. The system calculates not only the total construction duration, but also the operation and process idle-times based on the stories of the building.

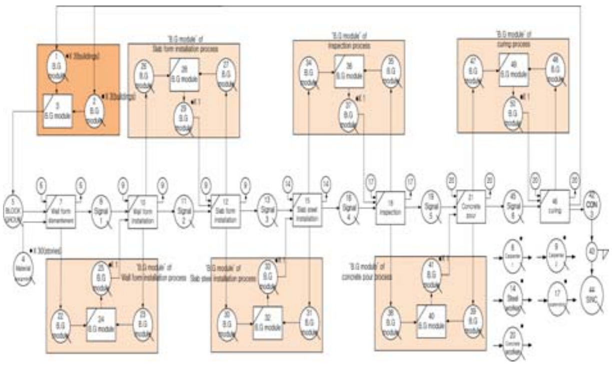

Figure 4. CYCLONE network model

3.4 Effectiveness inspection of the network model

The simulation analysis using the cyclone network model presented in Figure 4 shows the trace of event signals to validate the model. Figure 5 shows the events' finish times using the trace run function in Web-CYCLONE. It shows the sequence of the model executions involved in the three work zones.

First, COMBI 10 (wall form installation) captures the signal after executing COMBI 7 (wall form dismantlement). After passing the controlling signals through BG module, the signal of COMBI 7 (wall form dismantlement) receives the signal again. Then COMBI 12 (slab form installation) captures the signal. This means COMBI 7 (wall form dismantlement) has finished the process on work zone 1, and proceeded to the next work zone. The COMBI 10 (wall form installation) and COMBI 12 (slab form installation) are successive processes in work zone 1. In addition, when the signal is captured and released through the B.G modules, the simulation time will not be changed in the BG modules. It is because the BG modules are non-time-consuming logic components.

The shaded rows in Figure 5 represents the events occurred in work zone 1. The other rows show that a process is being performed in other work zones. It shows that the BG modules are working properly and reflecting the reality of space zoning at construction job-site. Therefore, it is confirmed that the model is capable of tracking the same process signal as the realistic construction process. As shown in Figure 1 and 5, the idle-time between operations is a waiting time caused when the crew in the process has finished the 'wall form dismantlement' process (②, ⑤, ⑧) for three work zone and returned to the second floor of the first work zone. However, it couldn't start the process on the second floor immediately because the 'concrete pouring' process (⑮) has not been completed yet. Therefore, it causes the waiting time of 20.7 between the point of 27.1, when the process ⑧ is finished and the point of 47.8 when the process ⑮ is finished. In other words, the crew of the 'wall form dismantlement' has operation idle-time of 20.7 in the first work zone.

The process idle-time indicates the waiting time which causes delay in process because the 'wall form installation' process(③, ⑪) is not finished for the previous work zone even though the 'wall form dismantlement' process(②, ⑤, ⑧) were finished. For example, even though the 'wall form dismantlement' process at work zone 3(⑧) is finished at 27.15, the 'wall form installation' process at work zone 3 couldn't be started until 36.7 because the 'wall form installation' process at work zone 2(⑪) is not finished yet. In other words, the work zone 3 will be paused during the time gap (9.55) due to the lack of working crews at the 'wall form installation' process.

SPACE ZONING PROCESS				
TRACE INFORMATION				
No.	Sim Time	Activity No.	Type	Name
①	0.0	3	COMBI	B.G module
②	8.7	7	COMBI	wall form dismantlement
③	16.2	10	COMBI	wall form installation
④	16.2	24	COMBI	B.G module
⑤	17.5	7	COMBI	wall form dismantlement
⑥	24.5	12	COMBI	slab form installation
⑦	24.5	28	COMBI	B.G module
⑧	27.1	7	COMBI	wall form dismantlement
⑨	36.0	15	COMBI	slab steel installation
⑩	36.0	32	COMBI	B.G module
⑪	36.7	10	COMBI	wall form installation
⑫	36.7	24	COMBI	B.G module
⑬	39.5	18	COMBI	inspection
⑭	39.5	36	COMBI	B.G module
⑮	47.8	21	COMBI	concrete pouring
⑯	47.8	3	COMBI	B.G module
⑰	47.8	40	COMBI	B.G module
⑱	49.4	12	COMBI	slab form installation
⑲	49.4	28	COMBI	B.G module
⑳	55.9	7	COMBI	wall form dismantlement

Figure 5. Result of CYCLONE model simulation

4. SPACE ZONING DECISIONG SUPPORT SYSTEM

The idle-time is calculated based on the simulation outputs of the CYCLONE network model presented in section 3. In addition, the numerical data regarding idle-time based on the number of combinations of space zoning and the system prototype which supports space zoning decision are presented. To increase readability, the system user environment and the approach differentiated from existing studies are explained. The function of the system is described as follows;

- Inputting the value for each attribute (or variable) relative to space zoning decision. Main variables include the number of work zones, stories, process crews, and duration of each process in a construction zone.
- Depending on the total number of work zones, the user decides the space zoning scenario (e.g., whether

to divide 10 buildings in 2 work zones or 3 work zones). There are numerous numbers of space zoning combinations, but the user should exclude inefficient scenarios.

- By integrating BG module into the network model as slave-pattern, the CYCLONE performs simulation for space zoning scenarios.

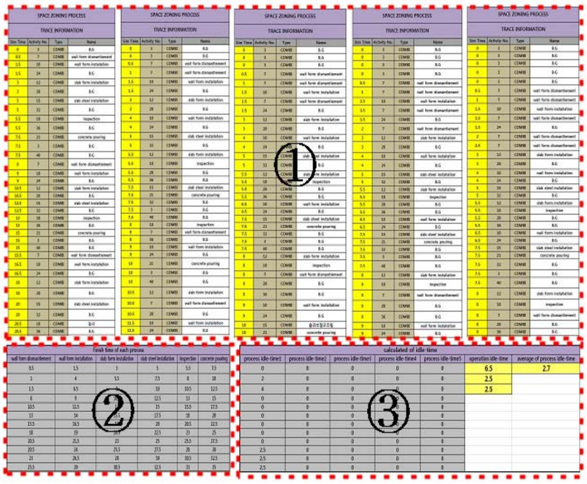

Figure 6. Prototype system of idle-time calculated

- Saving the CYCLONE trace run values according to the space zoning scenarios in Excel (① in Fig. 6).
- Extracting and saving finish time of each process which is required for calculating idle-time (② in Fig. 6).
- Calculating operation idle-time and process idle-time with macro function (③ in Fig 6).
- After calculating the idle-time between all processes and operations, this system shows the average idle-time. The user establishes standard to decide space zoning by setting the average idle-time as the object function.
- Decision-making for space zoning using the results in Fig. 6. The user inputs each process duration on the critical path for structure construction based on the situation on the construction field using user interface shown in Fig. 7.

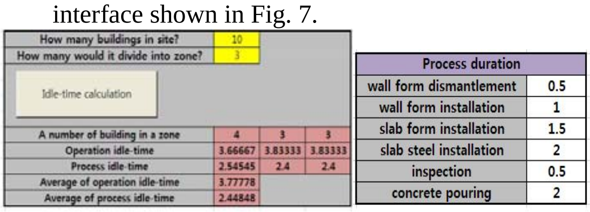

Figure 7. User interface of space zoning system

- Finally, the user inputs the total number of work zones and how many construction zones they want to divide them into, before clicking 'idle-time calculation' button, to check the idle-time based on the result in Fig. 6. For instance, when a user needs to identify which plan is effective between dividing two or three construction zones if a construction zone has ten work zones, the user specifies '2' or '3' at the input command window. If the user inputs '2', the average idle-time will be calculated dividing two of '5' work zones. If the user inputs '3', the average idle-time will be calculated dividing '4', '3', and '3' work zones. Supposing every floor plan of the working zone is identical, the optimal plan of dividing construction zones is calculated automatically based on the number of the space zoning which the user specified.

5. CONCLUSION

This paper develops BG. module by using DES (e.g., CYCLONE) for efficient space zoning of condominium structure construction. It can be reused for improving practical applicability. Users may use it simply by changing the input values depending on the job-site condition, even if they do not have professional knowledge in simulation. The space zoning module can be modeled by arranging the processes which move in a work zones in order, finding critical path, and applying BG. module with the slave-pattern for each process. The users can reuse the module in any operation by specifying how many work zones that they want to group as one construction zone, and the number of stories in a work zone. In addition, by calculating the idle-time between operations, the investigated space zoning combination with the minimum idle-time is presented. The system prototype takes into account different process durations in different job-sites, finds the optimal space zoning combination, and provides an opportunity to make an objective space zoning decision by calculating actual idle-times.

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