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An Object-Oriented Simulation System for Construction Operations

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ABSTRACT

This paper presents the methodology for simulating the process of construction operations by using object-oriented approach. Authors developed a prototype system to model construction operations and to simulate their behavior at site, which included the random effects of weather and productivity in operations. Through the implementations of this prototype system, authors concluded the object-oriented simulation system would be a competent tool for improving construction process.

1. INTRODUCTION

In construction planning, it has not been possible to apply the feed-back information to rationalizing the process as is done in the planning for repetitive productions. Therefore, it is extremely important to simulate the construction process during construction planning stage and to point out problems in advance. However, system simulation techniques require considerable time and manpower, which makes its use difficult for ordinary construction planning.[1]

This study aims at establishing a methodology for system simulation of the construction process to enable its effective use in construction planning, as well as developing a prototype system. In this paper, a method is proposed that represents construction activities in a more sophisticated and precise way than conventional methods by applying an object-oriented simulation model to represent construction activities, and case studies are presented.

2. SYSTEM SIMULATION

Recently, simulation technologies have been widely used in industry. With advances in computers, many languages (e.g., STELLA, a continuous type, and SLAMSYSTEM, a discrete type) with excellent interfaces that feature graphics and mouse operation have emerged. In addition, SLAM & TESS and CIMAN & CINEMA have made it possible to represent simulation results in graphics. Recent research focuses on the application of knowledge representation methods to simulation models.

Applying simulation to construction was introduced in the 1970s, when many models were made using GPSS. In the 1980s, DYNAMO and SLAM were introduced, and the method of making effective models with graph notations as well as the method of representing simulation results using graphics and animation were developed.[2)3)4)] However, since complex logic is involved in the construction process and various uncertain factors are encountered at real construction sites, conventional procedural languages cannot describe real events adequately. Therefore, an approach based on knowledge engineering has become necessary.

An object-oriented approach has the advantage of grasping many intricate events individually and independently in a simulation model, thus it would be suitable for construction simulation.

3. OBJECT-ORIENTED SIMULATION

3.1. Object-oriented model

An object-oriented model strictly defines each element existing in the real world as an object. By defining each action of each object as methods in the object itself, the explicit representation of sophisticated models, their debugging, and their modification are facilitated.

Representing an object in a hierarchical structure makes it possible for lower objects to inherit rules and attributes from an upper object. This causes simulation models to be much simpler.

Some general-purpose object-oriented simulation systems such as SIMULA and KEE & SIMKIT have already been developed. Because the object-oriented simulation grasps the structure of the real world as a knowledge model, the run time of simulation is much longer than that of conventional ones. This makes object-oriented simulation unfavorable for solving problems that require many simulation repetitions due to random factors. On the other hand, object-oriented simulation has the ability to represent logics in the real world more freely than the conventional languages and has the advantage of making models closer to the real world by using rules and methods. In particular, the effect of the object-oriented simulation on sophisticated models, including a construction process, is significant.

3.2. Knowledge representation of logics in construction process

The knowledge-model simulation uses an algorithm based on rules and methods to simulate activities. The use of rules makes it easier not only to simulate the construction process but also to predict the future process and modify the planning of the process.

Moreover, this system can make precise models of work areas, as well as move locations, routes, and transportation of equipment, all of which have been difficult to represent with conventional simulation languages.

3.3. Functions required in the simulation system for construction

The simulation system simulates, step by step, the construction status, according to each period based on the construction plans and instructions which users input during each construction period, and it outputs the results.

This simulation system requires the following functions:

(1) To advance the construction process by the various intervals of 1 day, half day, 1 hour, 1 minute, 10 seconds, or 1 second, according to its purpose.

(2) To generate or change events chronologically which affect the construction process.

(3) To represent the construction process as a set of activities.

(4) To start/finish activities, according to the precedences and the time lags between activities.

(5) To determine the work speed by considering uncertain factors, once activities have started.

(6) To determine the work speed according to the amount of construction resources, after confirming the necessary amount of resources.

(7) To attain the targeted construction period by increasing and decreasing the construction resources, in cases where the target is set.

(8) To vary the attributes of space according to the activities and the resources existing in the space, and to restrict those performances in the space.

(9) To grasp chronologically the position of construction resources which

are moved by activities.

3.4. The structure of an object

Fig.1 describes a hierarchical structure of objects used in the simulation. Objects consist of CONTROL Object which manages the whole simulation, CLOCK Object which manages time, and ELEMENT Objects which represent the process. Each ELEMENT Object is composed of ACTIVITY, SUBSTANCE, EVENT and SPACE. Each object functions as follows:

(1) CONTROL: To manage interfaces between users and system, with TIME KEEPER which controls the flow of time at the lower level.
(2) CLOCK: To manage time during the construction period.
(3) ACTIVITY: To perform activities.
(4) SUBSTANCE: To manage the allocation of construction resources to activities.
(5) EVENT: To control the occurrence and extinction of events.
(6) SPACE: To manage the spaces of work area and stockyard.

Fig.2 shows the structure of these objects. In the simulation, events occur in response to time which is managed by CLOCK Object. With these events, the situations of resources such as workers, equipment and materials are changed, and activities are advanced.

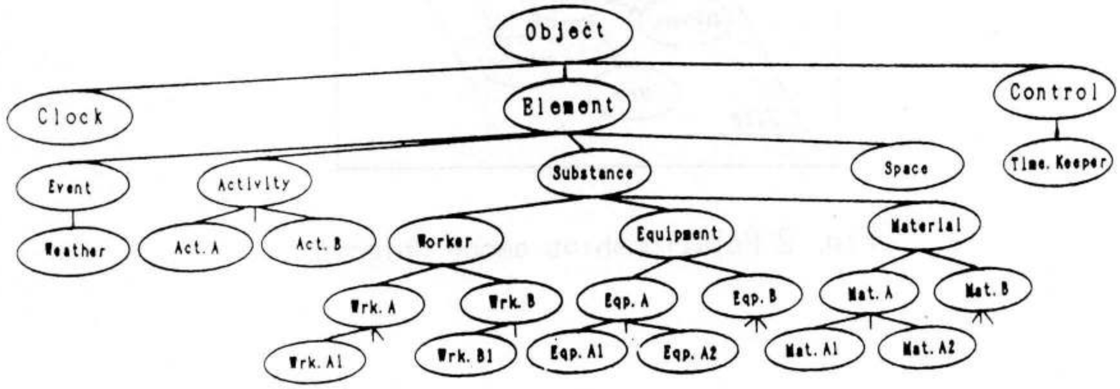

Fig. 1 An Hierarchical Structure of Objects in Simulation

3.5. Slots and methods of an object

Table 1-3 shows slots and methods of three major objects, CONTROL, ACTIVITY and WORKER, which play an important role in the simulation.

The procedures in allocating workers to activities and in deciding the start/finish of activities are conducted by changing the slot values through the exchange of messages between these objects.

4. APPLICATION OF A PROTOTYPE SIMULATION SYSTEM TO CONSTRUCTION

4.1. The construction process for a case study

Reinforced concrete work in building construction was selected as the case study of this paper. The activities on the specific floor were simulated. The activities on each floor are divided into three blocks. Fig.3 shows the network diagram of the construction process of the activities in each block. Table 4 shows the work volume, work rate, types of workers required, and the number of workers in each block. The work volume in each block is the same.

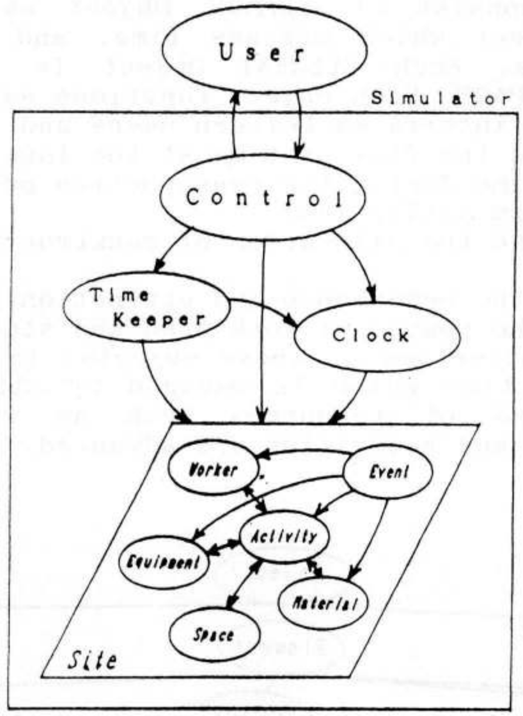

Fig. 2 Relationships among Objects

Table 1 Slots and Methods of Control Object

Control objects	
Slot	Discription
Decision. Interval	Interval time of instruction
Activity. command	Instruction of activity requirement
Holiday	Lists of holidays
Resource. command	Instruction of resource requirement
Work. finish. time	Time to finish work
Work. start. time	Time to start work
Method	Discription
Decision. interval. input	Inputing decision interval
Start. time. input	Inputing start time
Finish. time. input	Inputing finish time
Holiday. input	Inputing lists of holidays
Command. activities	Transfering instruction of activity requirement
Command. resources	Transfering instruction of resource requirement

Table 2 Slots and Methods of Activity Object

Activity objects	
Slot	Discription
Act. command	Instruction of activity requirement
Condition. research. data	Climate conditions
Finish. time	Finish time
Necessary. resource	Necessary resources (name and unit)
Network. research. data	Precedences
Position	activity location
Position. research. data	Space conditions
Resource. research. data	Resource conditions
Resource. updown. research. data	Upperlimit of work team
Situation	Status of activity
Start. time	Start time
Team	Number of teams working
Team. occupy. space	Space occupy
Team. rate	Work rate by a team
Time. research. data	Time condition
Work. left	Work left
Work. rate	Work rate
Work. space	Work space
Work. volume	Total work volume
Method	Discription
Activity. manager	Managing
Condition. research	Checking climate condition
Network. research	Checking precedences
Position. back	Releasing space
Position. check	Checking space
Position. get	allocating space
Position. research	Checking space availability
Position. reserve	Occupying space
Resource. back	Releasing resource
Resource. check	Checking resource allocation
Resource. get	allocating resource
Resource. research	Checking resource availability
Resource. updown. research	Estimating possible number of teams
Resource. work	Activating resource to work
Resource. work. stop	Deactivating resource
Time. research	Checking duration
Work. rate. decision	Estimating work rate with teams
Working	Performing work

Table 3 Slots and Methods of Worker Object

Worker class object	
Slot	Discription
All. number	Number of workers
Left. number	Number of workers not working
Original. position	Position of depot
Resource. data	Status of workers
Move. speed	Speed of moving
Command	Instruction of worker requirement
Method	Discription
Worker. manager	Managing worker objects
Worker. availability	Dispatching workers
Resource. allocation	Allocating workers
Worker. come. home	Removing a worker unit
Create. worker	Creating a worker unit
Worker. availability. note	Recording status
Worker instance object	
Slot	Discription
Current. position	Current position
Target. position	Target position
Situation	Status (0:not available, 1:moving to work site, 2:moving to the station, 3:working 4:waiting, 5:available)
Method	Discription
Worker. Action	Activate workers to move

Table 4 Attributes of Activities

Activity	Total Task	Task per Workforce	Workforce in a Team Reinforcement	Workforce in a Team Formwork
ACT.BEAM.FORMWORK.1	240	51		4
ACT.BEAM.REINFORCEMENT.11	9	1.6	4	
ACT.BEAM.REINFORCEMENT.12	9	1.6	4	
ACT.COLUMN.FORMWORK.11	67	40		4
ACT.COLUMN.FORMWORK.12	67	51		4
ACT.COLUMN.REINFORCEMENT.1	6.1	2.3	5	
ACT.CONCRETE.POURING.1	140	420	2	2
ACT.EXTERNAL.WALL.FORMWORK.11	116	59		4
ACT.EXTERNAL.WALL.FORMWORK.12	117	59		4
ACT.EXTERNAL.WALL.REINFORCEMENT.1	1.7	0.9	5	
ACT.INTERNAL.WALL.FORMWORK.11	50	59		4
ACT.INTERNAL.WALL.FORMWORK.12	50	59		4
ACT.INTERNAL.WALL.REINFORCEMENT.1	1	0.9	3	
ACT.MARKING.1	300	200		
ACT.PRE.FABRICATE.FORM.PRE.FAB.11	167	400		10
ACT.PRE.FABRICATE.FORM.PRE.FAB.12	333	800		10
ACT.PRE.FABRICATE.FORM.PRE.FAB.13	457	533		10
ACT.SLAB.FORMWORK.11	183	77		5
ACT.SLAB.FORMWORK.12	33	77		5
ACT.SLAB.REINFORCEMENT.1	3.3	1.3	4	
ACT.STAIRS.FORMWORK.1	100	50		4
ACT.STAIRS.REINFORCEMENT.1	3	1.5	5	

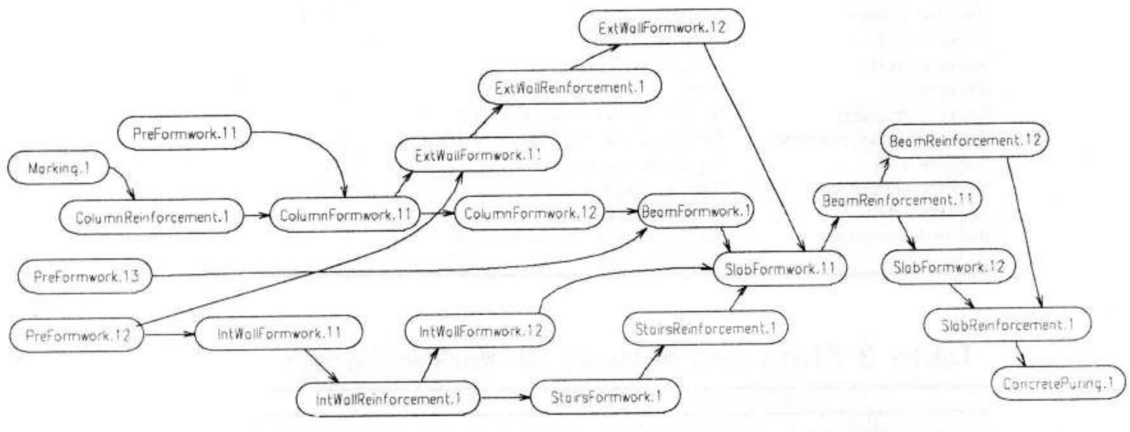

Fig. 3 Network Diagram of the Reinforced Concrete Works

In this construction process, primarily reinforcing-bar placers and formworkers were allocated, according to the priority of activities. The priority was decided on their basis of the total float, the start time, and the duration of the activities.

This simulation system takes into account the uncertain factors such as rain and temperature, and examines the effects on the discontinuance of activities and on the decrease in productivity.

f4.2. The execution of simulation

The simulation was executed using the system made on KEE platform. Fig.4 shows the structure of objects on KEE.

Two cases in the construction process mentioned above are examined; in the first case, the allowable number of teams in each activity is two, and in the second case, the number is three.

Fig.5 shows the daily schedule when the allowable number of teams in each activity is two. The lower part of the figure shows the time zone of

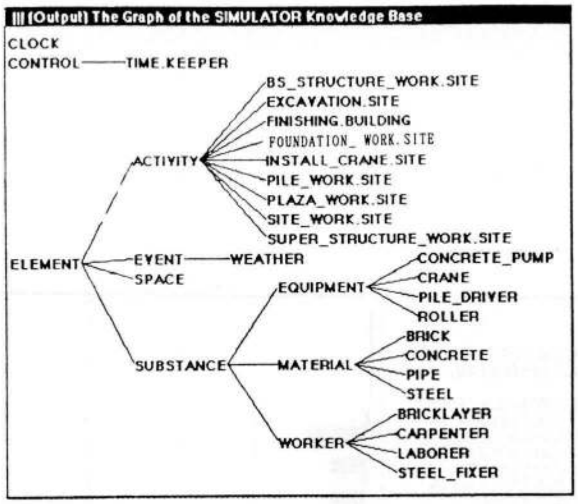

Fig. 4 Object Structure in KEE Platform

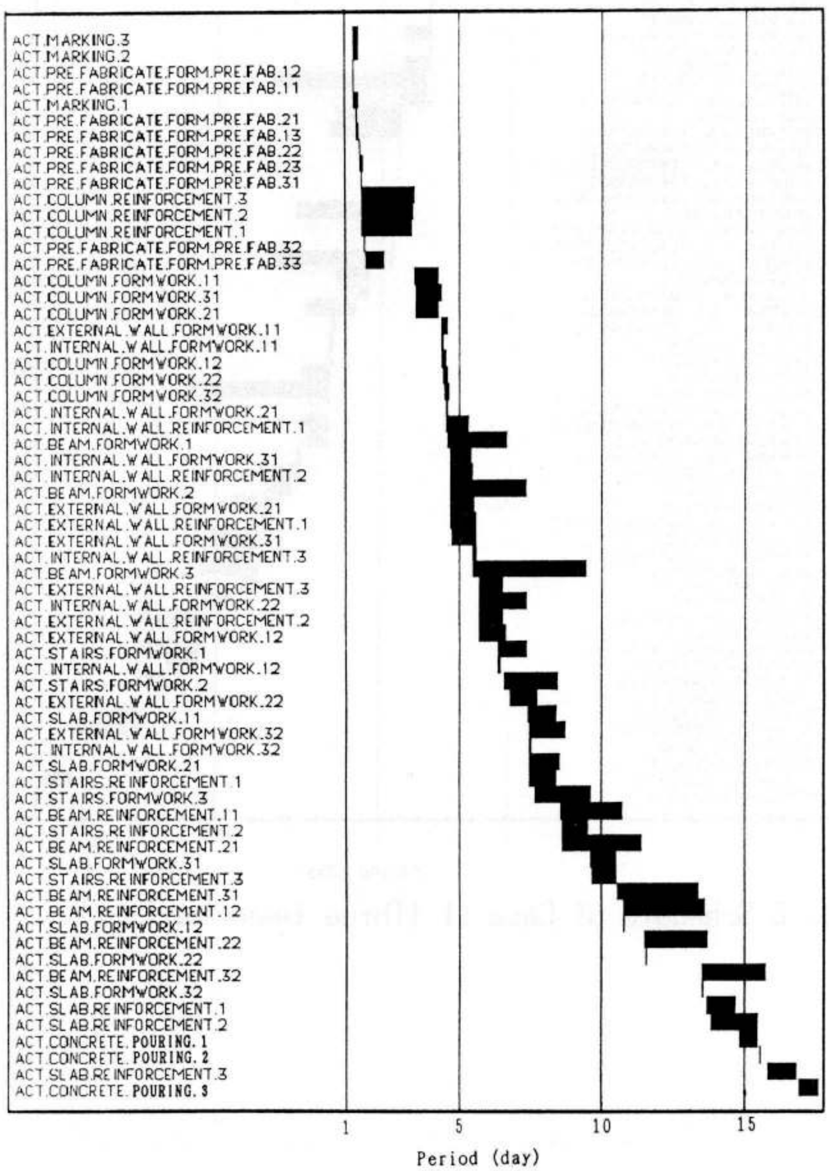

Fig. 5 Schedule of Case I (Two teams maximum)

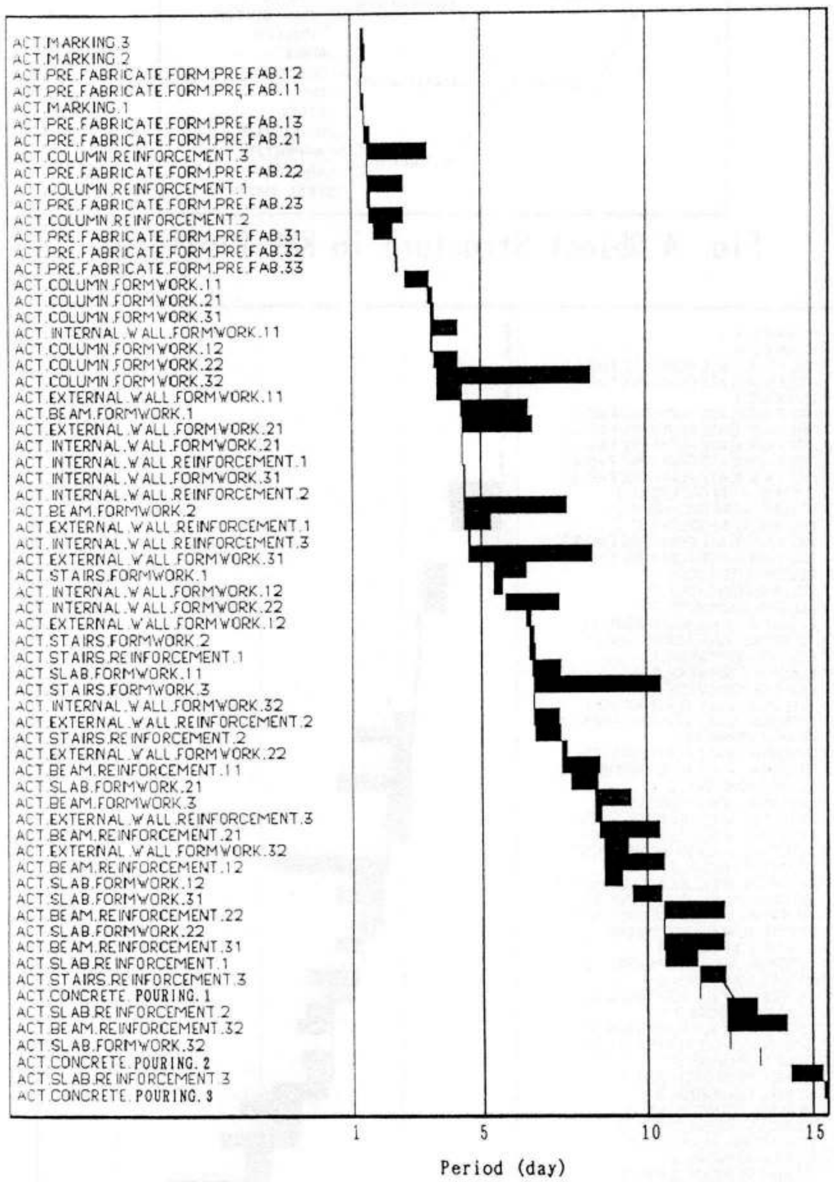

Fig. 6 Schedule of Case II (Three teams maximum)

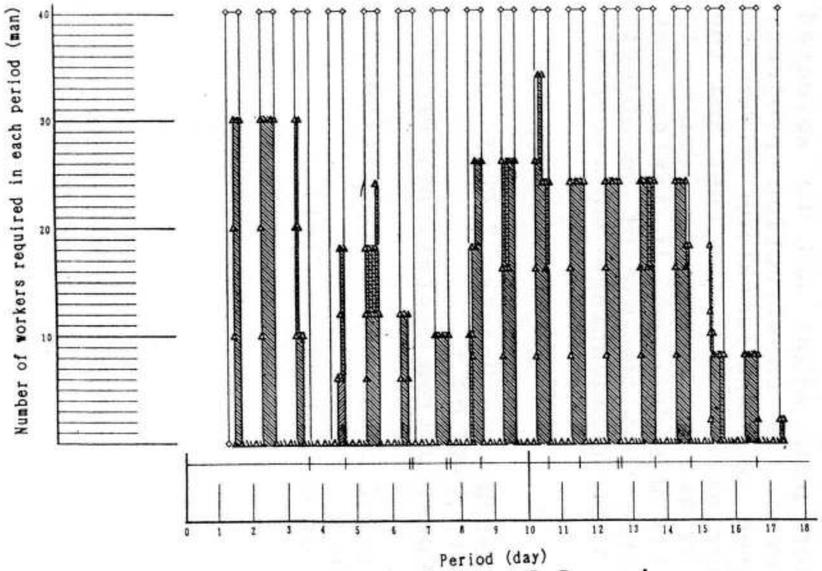

Fig.7. a Reinforcing-bar Workers of Case I

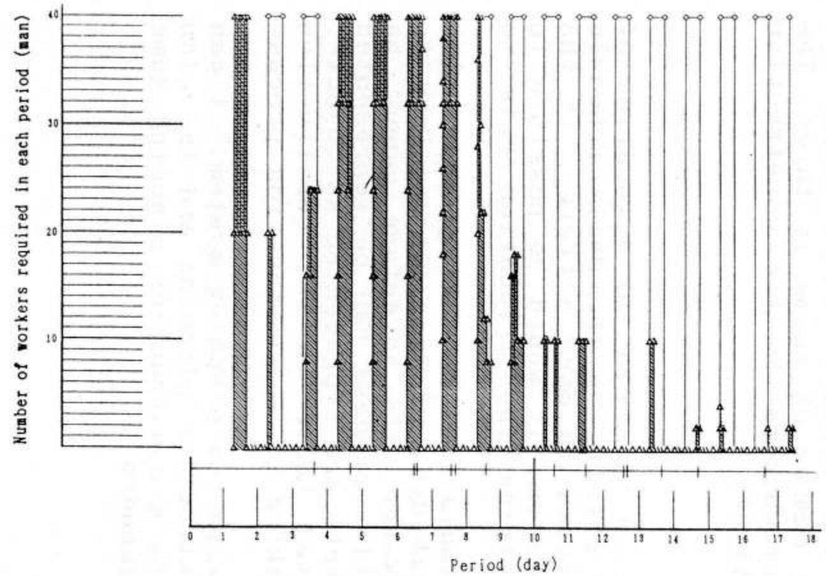

Fig.8. a Formwork Workers of Case I

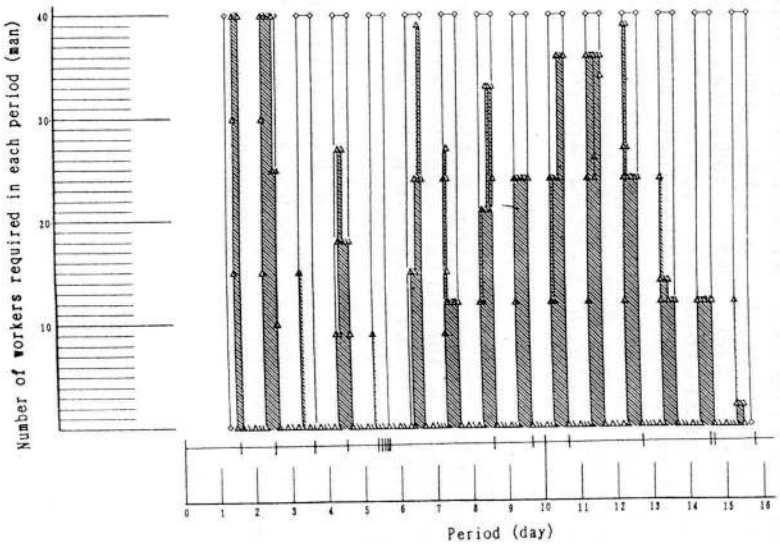

Fig.7. b Reinforcing-bar Workers of Case II

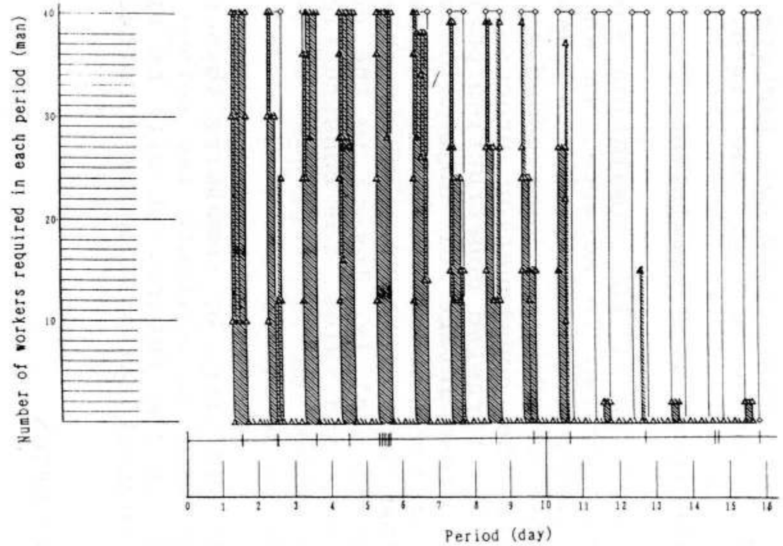

Fig.8. b Formwork Workers of Case II

the discontinuance of activities due to the weather. Fig.6 shows the results of the case in which the allowable number of teams is three. The numbers of reinforcing-bar placers and formworkers in the construction period are shown in Fig.7 and Fig.8, respectively.

4.3. The results of simulation

Execution of the simulation was based on the rule for allocation of workers prepared in advance, in which the effects on the daily schedule were examined, by changing the number of teams in each activity. If the subsystem of planning were added to this system, it would be possible to simulate the construction process by modifying the allocation rule to attain the targeted construction period.

A disadvantage of object-oriented simulation is the greater time required for the simulation, because a great deal of time is required in handling the information of an object. However, its advantage cannot be neglected; that is, logics in the construction process can be represented as methods and rules, for construction elements are represented as objects. This enables us to represent a complicated logic in the construction process as a model, and facilitates the making of a construction process model.

In addition, by combining this system with the planning system, it can also be used to evaluate the method of construction planning and the plan itself. In the future, it will be applied to a construction planning game as an educational system for construction planners.

5. CONCLUSION

Because construction activities are not repeated under the same conditions, the appropriateness of construction planning cannot be evaluated correctly even after the completion of the project. Therefore, construction plans have been evaluated only ambiguously, which is one of the reasons why an alternative construction plan might not be selected appropriately based on past records. However, as construction projects become larger and more complex, the degree of consideration given to uncertain conditions in construction planning will affect the cost and the period significantly. Although application of the simulation is limited to parts of construction projects because of its disadvantage in taking much time and manpower for modeling, it is expected that the use of an object-oriented simulation system would overcome this disadvantage to a certain degree.

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