

Chapter 6

Applications of the Integrated System

6.1 Introduction

In order to illustrate the potential of the Integrated System to support integrated decision-making of construction planners, this chapter illustrates the potential of the Integrated System applications. Time-motion and cost analysis is a main application of the system. The applications involve construction space management such as: 1) construction-site layout, and 2) space conflict and safety analysis.

6.2 Application of Integrated System for Time-Motion and Cost Analysis

In construction operations, different construction methods can generate different construction time and cost. Thus, the project manager should optimize the construction techniques in order to optimize construction time and cost. In this chapter, an application of the Integrated System for time-motion and cost analysis in a virtual reality approach is described in detail and some case studies are illustrated.

6.2.1 Work Study

6.2.1.1 Definition

Work study is defined as “ A measurement service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead to the systematic investigation of all resources and factor which affect the efficiency and economy of the situation being reviewed, in order to effect improvement” (The British Standard: BS 3138:1969).

According to this definition, work study consists of two important parts namely: 1) method study and 2) work measurement (See details in Figure 6.1).

6.2.1.2 Method Study

Method study is the technique used to record work procedures to provide systems of analysis in order to develop improvements (Harris, 1989). This technique can be applied in project planning, designing of temporary work, distributing plant and other resources at the work place, re-planning and progressing of production.

6.2.1.3 Time Study or Work Measurement

Time Study or Work Measurement is the measurement of the time required to perform a task (Harris and McCaffer, 1989).

An output standard of production for workers, machines or both of them may be established. It may be used as information for process estimation or as a part of the data in the method study. It can be also used to monitor actual production performance.

6.2.2 Time –Motion Analysis

In construction project operations, project managers or planners must select the appropriate construction methods for each construction activity. Different construction methods can generate different construction durations. Thus, in order to analyze construction methods and sequences in detail, time-motion analysis is applied to improve the productivity of construction activities by adapting work-study concepts.

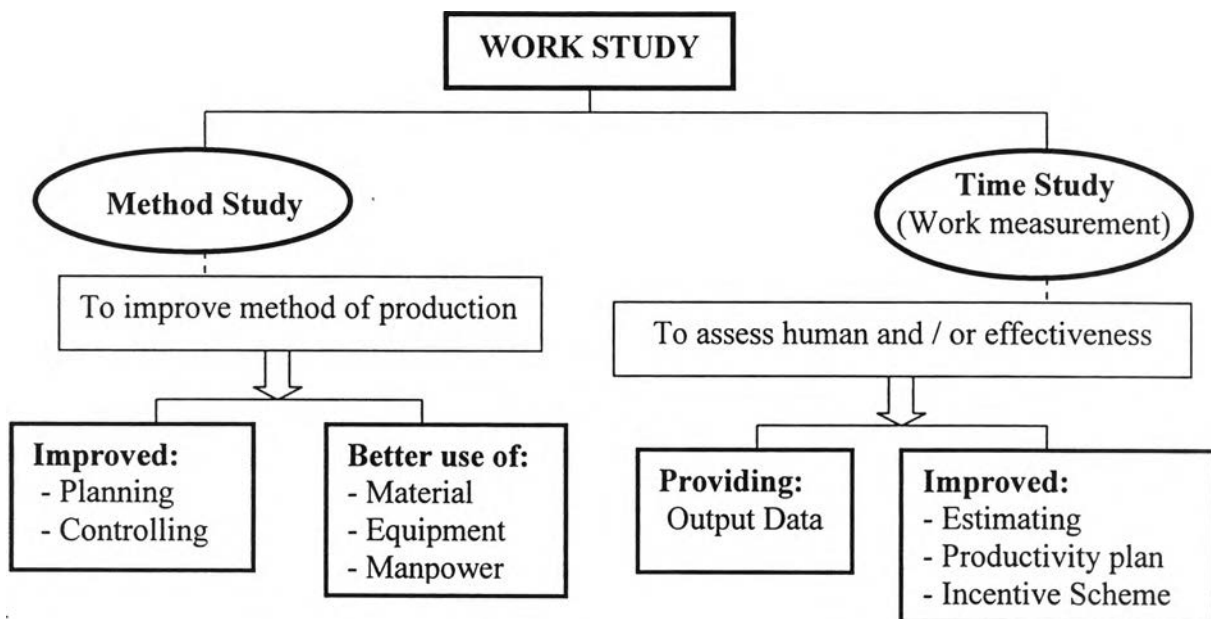


Figure 6.1: Structure and benefits of work-study (Source: Harris and McCaffer, 1989)

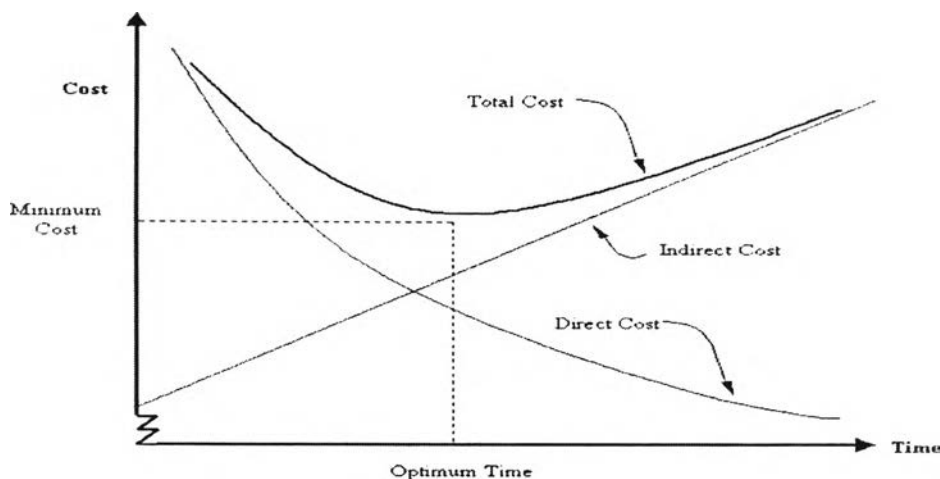


Figure 6.2: Relationship among direct cost, indirect cost and time

6.2.3 Time-Cost Analysis

In time-motion, different construction methods can generate different construction durations. In time-cost study, different construction duration can generate different costs. In general, construction cost consists of direct cost and indirect cost. If the

construction duration is shortened, the direct cost will increase. On the other hand, if the construction duration is expanded, the indirect cost will increase as shown in Figure 6.2.

Consequently, project planners should determine the optimum construction duration in order to get minimum total cost.

6.2.4 Time-Motion Analysis by Virtual Reality Approach

Because of the advantages of the Virtual Reality (VR) approach, which can illustrate models in three dimensions and time, it is an interesting tool to be applied to present construction activities in virtual space.

6.2.4.1 Time-Motion Study of One Machine Operation

Example Case

Case I: Time-motion study of pile-driving machine for pile-driving activities

In this case, the pile driving-machine is typically used in Thailand. It consists of three main components, namely the rail, the tower and the hammers. There are different heights of the towers and different weights of the hammer. The operation cycle of the pile-driving machine is divided into the following activities: 1) dragging pile to driving position, 2) installing pile to its position, 3) setting pile vertically, 4) pile capping, 5) pile driving, 6) pile connecting; 7) blow-count checking, 8) changing the position of the driving machine by moving the tower or rotating the rail, and 9) setting the driving machine to the next pile's position. The steps and sequences in the operation cycle are presented in Figure 6.3.

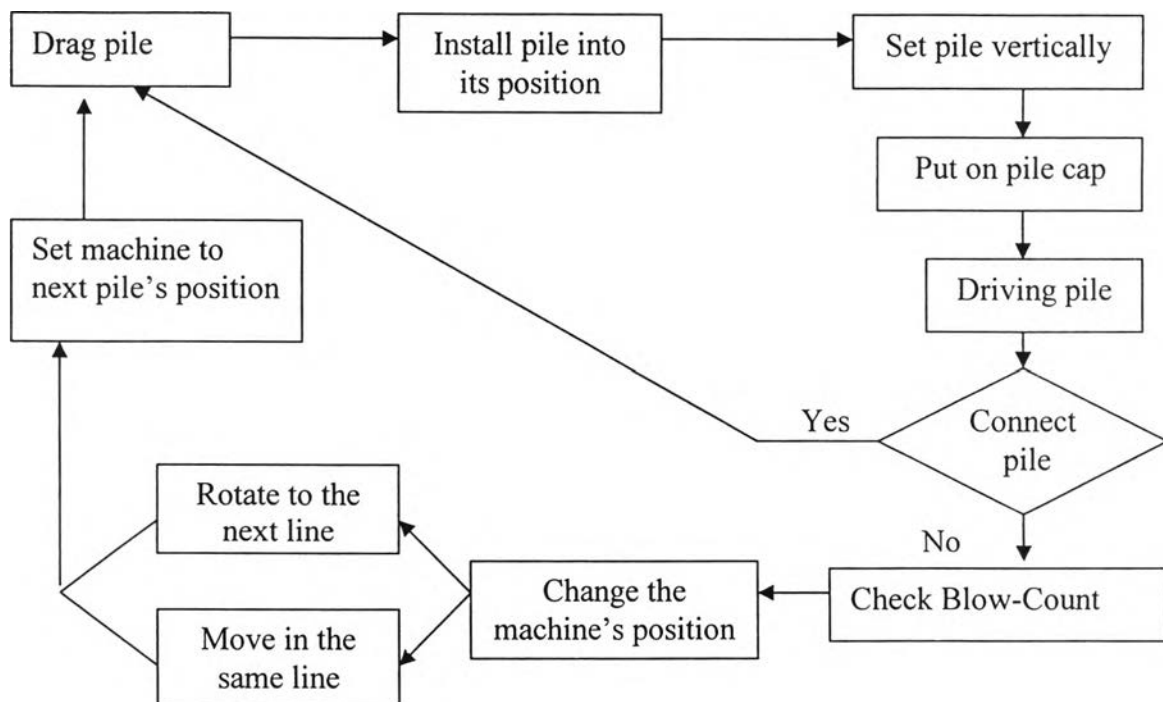


Figure 6.3: Flow chart of operation cycle of pile-driving machine

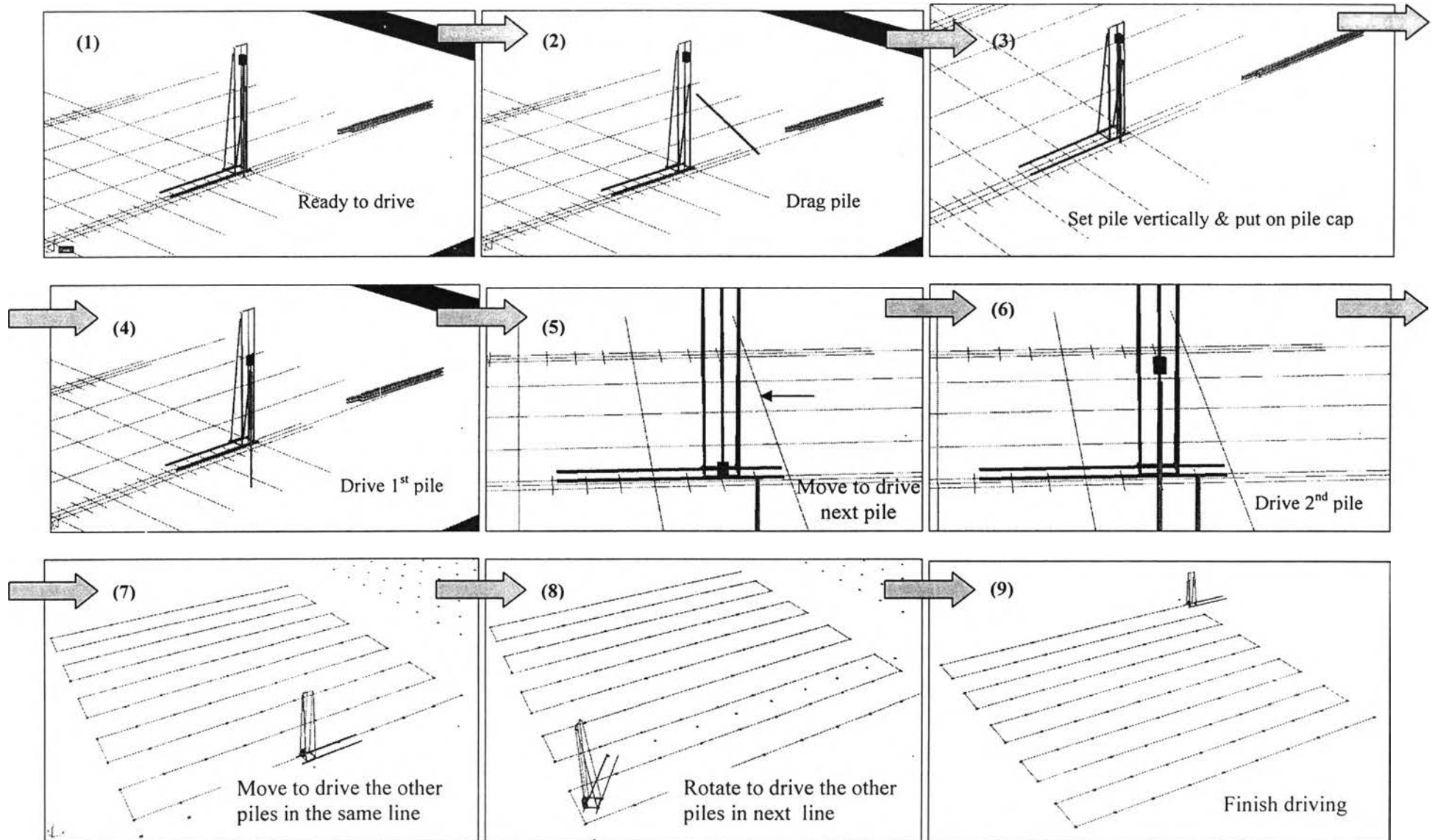


Figure 6.4: Operation cycle of pile driving presented in virtual reality space

In Figure 6.4, the operation cycle of pile driving is presented in the VR space of the Integrated System. It illustrates the motion of the pile-driving machine and driven piles. Time-motion study of pile-driving activity involves the steps of changing the position of the driving-machine via two types of motion, which are 1) changing its position by moving the tower straight to the next position of piles and 2) changing its position by rotating the rail to the next line of piles.

According to the approach of the method study, the method of pile-driving activity is an example of motion analysis of the pile-driving machine. The different motions of construction machines can generate different activity durations. Consequently, the construction planner must select the appropriate motion for the construction machine to get the optimum duration of construction activity. Project planners must have extensive experience in construction management in order to select the appropriate moving path of construction machine. If they lack experience, project managers will require a tool that can help them analyze the construction method in detail. The VR approach in the Integrated System can help project managers effectively analyze the construction methods in details since it can illustrate the construction techniques and sequences in VR space, as they will proceed during the actual construction process. Thus, project managers can examine the details of construction. For example, they can observe the motions of construction machines in three dimensions (3D) and can select the appropriate construction sequences so that they are able to plan the construction within the optimum duration.

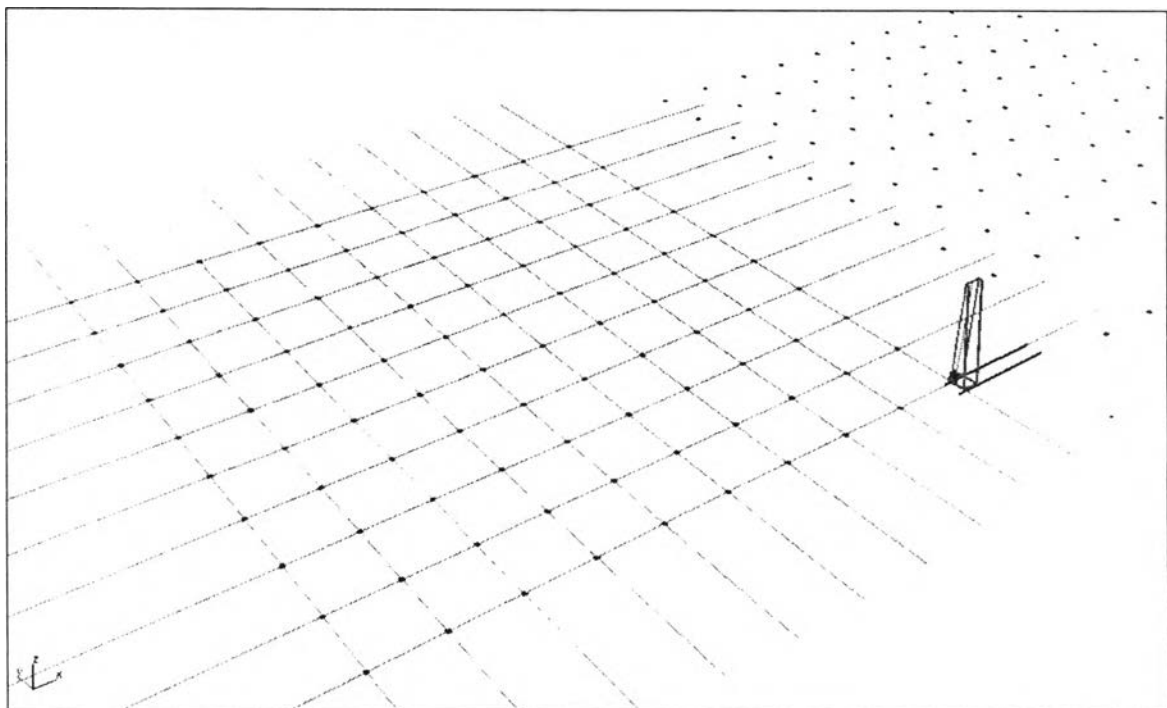
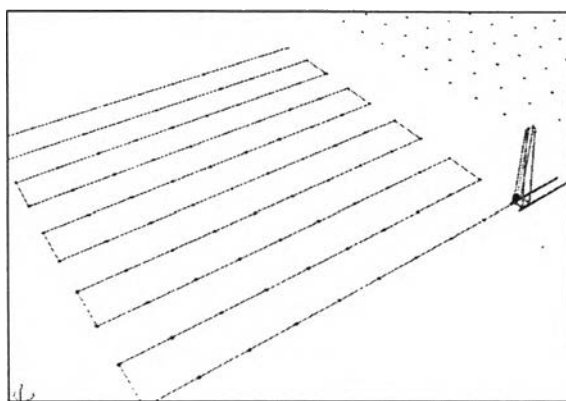


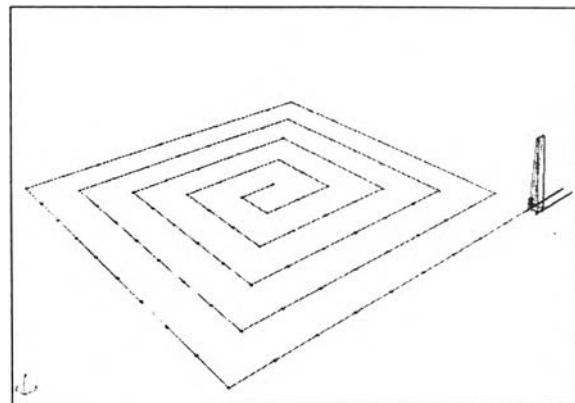
Figure 6.5: One hundred piles (10X10 lines) are driven by a pile-driving machine

According to pile-driving activity, pile-driving machines can be relocated or changed their position by moving the tower straight to the position of the next pile and rotating the rail to the next line of pile. These motions require different durations. In general, the time used for rotating the rail of a pile-driving machine to the next line is usually longer than the time used for moving the tower in the same line.

For example, the one hundred piles (10 X 10 lines) shown in the Figure 13.5 will be driven by one pile-driving machine. When project managers consider the appropriate path for pile driving, the path which requires the minimum numbers of rotation should be considered first. That path can be clearly observed in VR space so project planners can comfortably consider the appropriate path. In Figure 13.6, there are nine rotations required in path No.1 but seventeen rotations required in path No.2. Thus, the pile-driving machine would take more time to follow path No.2 than path No1. (Case No.2 is just the assumed case for comparison since it may not be performed in practice). Table 6.1 explains the results of the pile-driving analysis by Virtual Reality approach.



Pile-driving machine operates in path No.1



Pile-driving machine operates in path No.2

(assumed case study)

Figure 6.6: Motion analysis of pile driving by using a pile-driving machine

Table 6.1: Results of time-motion analysis of pile driving by one pile-driving machine.

Construction method	Work done	Machine moves in same line	Machine rotates to next line	Time spent to drive	Time spent to move	Time spent to rotate	Total simulation time
Pile-driving machine in path No.1	100 piles	90 times	9 times	Random 12 to 35 Min.	Random 10 to 15 Min.	Random 15 to 25 Min.	3651 Min. or 60.85 Hrs.
Pile-driving machine in path No.2	100 piles	100 times	17 times	Random 12 to 35 Min.	Random 10 to 15 Min.	Random 10 to 20 Min.	3845 Min. or 64.0 Hrs

6.2.4.2 Time-Motion Study of Multi-Machines Operation

In general, construction activities involve construction machine operations. At the construction sites, several types of construction machines are used to operate construction activity. Sometimes numbers of machines of each type consist of more than one machine. Thus, it is important for project managers or planners to manage those machines in order to optimize construction time and cost. Project managers or planners should consider not only the types and numbers of construction machines, but also their methods of operation.

The motion or movement of construction machines and building components should be carefully considered by construction planners.

Example case

In this research, factory building is used as a case study to implement the Integrated System operation. The Integrated System assists construction planners to consider and determine process simulation, time, and cost.

Case II: Time-motion and cost study of steel column and roof-truss installation

In this case, two factory-construction activities are operated, namely column installation and roof-truss installation. Three types of construction machines are selected to perform these activities: 1) the truck-crane, 2) the mobile-crane and 3) the excavator. Two truck-cranes are used to load, move, and install steel columns. One excavator is used to move and locate roof trusses from the prefabricating area to the installation location. A mobile-crane is used to lift and install those roof trusses as illustrated in Figure 6.7.

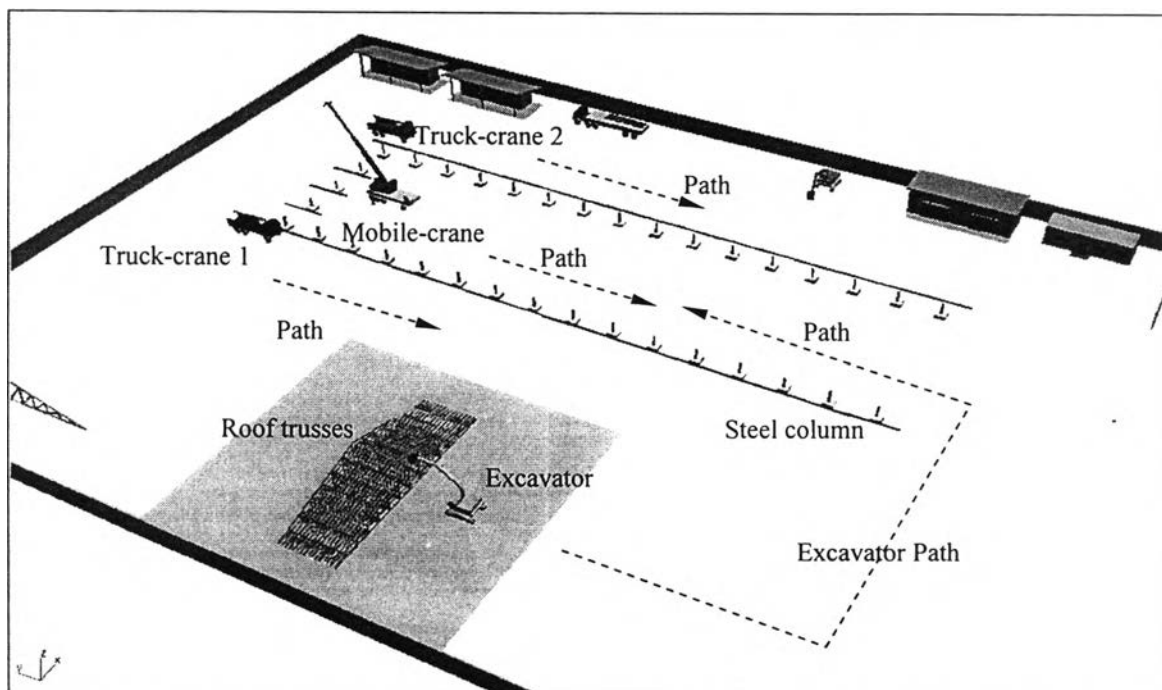


Figure 6.7: Installation of columns and roof-trusses of factory building considered in virtual reality approach.

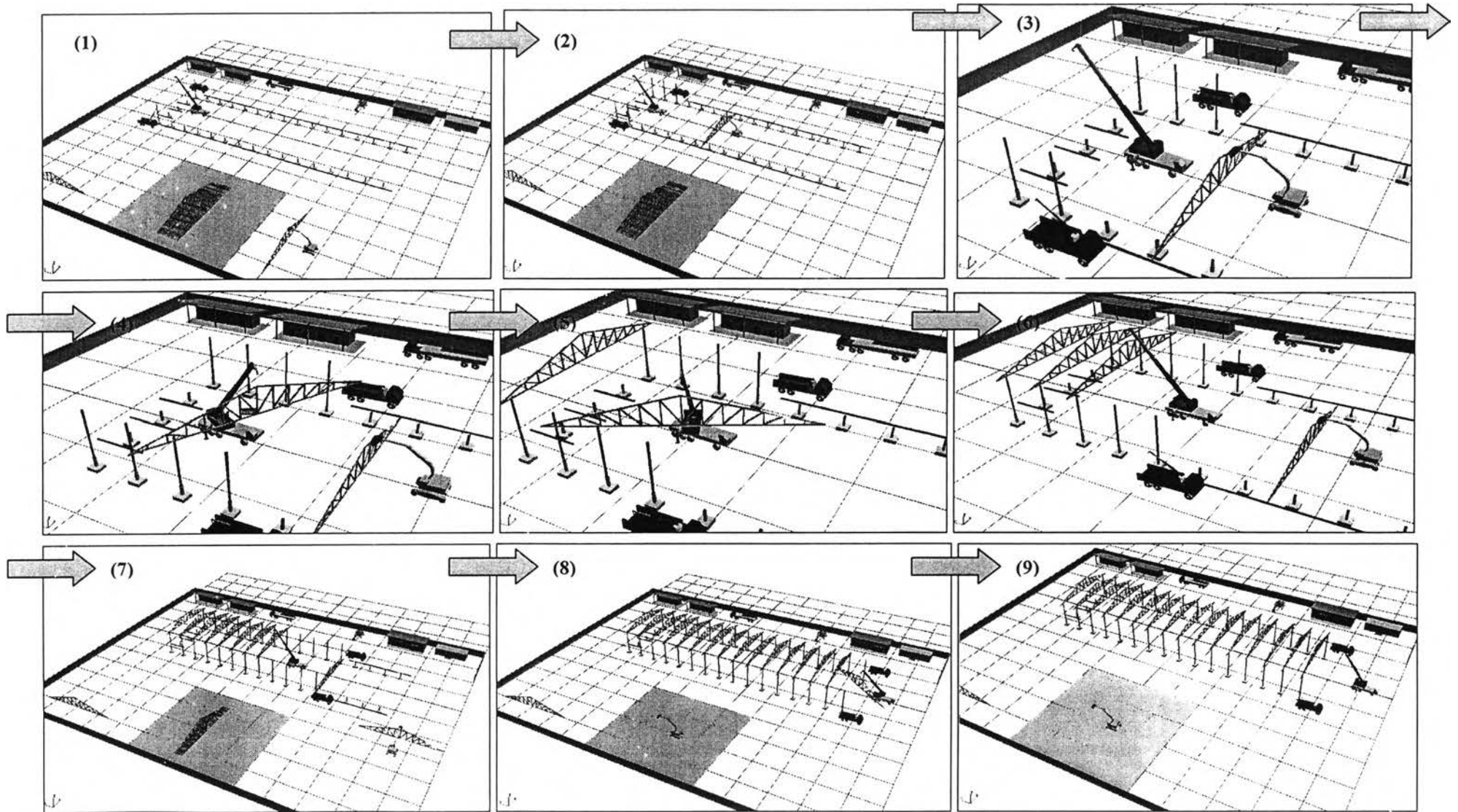


Figure 6.8: Motion of construction machines used to install columns and roof-trusses of factory building in virtual space

With the Integrated System, the factory-construction activities are considered by using the virtual reality approach. After project planners select the types and numbers of construction machines, the 3D models of construction machines from the machine library and 3D models of building components from the CAD drawing are imported into the virtual space of the visualizer. After that, operation paths and movement patterns of the construction machines and building components are assigned by looking closely at details. The virtual reality approach of the Integrated System can help project planners effectively analyze construction sequences and select the appropriate paths and movement patterns for those machines and building components.

In Figure 6.8, the project planners can set construction sequences for steel column and roof-truss installation as follows:

1) Two truck-cranes are used to carry and install steel columns. The first truck-crane carries and installs steel columns in the first line, and the second truck-crane is used to carry and install steel columns in the second line.

2) One excavator is used to carry and move one roof-truss per one time from the prefabricating area to the installation location.

3) One mobile-crane is used to lift, move, rotate and carry one roof-truss at a time until its installation is complete. Then it moves continuously to install the next roof-truss.

According to the potential of virtual reality approach, when construction planners examine these processes in virtual space, they can readily see that both truck-cranes can install only four columns at a time in their line, since steel columns that are installed more than four columns at a time will obstruct the carriage of roof-trusses by the excavator. Moreover, the maximum boom length of the mobile crane is limited. Consequently, both truck-cranes must wait until those roof-trusses are already installed before they can start to install the next column.

6.2.5 What-if Analysis: Case Study Illustration

6.2.5.1 Review

In order to illustrate the potential of the Integrated System, the time-motion and cost of some factory building activities are studied and analyzed using the virtual reality approach. The activities of factory building construction are appropriate construction activities to be simulated and analyzed using virtual reality approach since factory building construction consists of various repeated activities. For example, pile driving consists of several piles that are repeatedly driven by a pile-driving machine, and the mobile crane repeatedly installs steel columns and roof trusses. According to work study approach, different construction methods and sequences can generate different construction durations. Consequently, the construction planner should use “what-if”

analysis to select an appropriate construction method in order to optimize construction duration.

6.2.5.2 Definitions and Assumptions

- 1) What-if analysis is defined as “*What happens, if a condition is changed*”
- 2) Construction method refers to the assignment of the operation sequences, construction machine set (type, size and quantity), and machine paths.
- 3) Different construction methods can generate different construction durations.
- 4) Different construction durations can generate different construction costs.

Table 6.2: Details of case study (What-if analysis)

Approach	Construction Method	Construction Machine Set (quantities, types, sizes)	Activity (Installation)
<i>Approach I</i>	No. 1 (See Figure 6.9)	No. 1: 1-excavator type1. 2-truck-criteria type1. 1-Mobile-crane type1.	32 steel columns and 16 roof-trusses
<i>Approach II</i>	No. 2 (See Figure 6.10)	No. 1: 1-excavator type1. 2-truck-criteria type1. 1-Mobile-crane type1.	32 steel columns and 16 roof-trusses
<i>Approach III</i>	No. 3 (See Figure 6.11)	No. 2: 1-excavator type1. 2-truck-criteria type1. 1-Mobile-crane type 2.	32 steel columns and 16 roof-trusses

6.2.5.3 Time-Motion-Cost Study Using What-if Analysis

For factory-construction planning in virtual space using the Integrated System, project planners can use what-if analysis to select the appropriate construction sequences, construction-machine set, and machine operation paths. In this case, two activities of factory construction are used as example cases of time-motion study using what-if analysis and the virtual reality approach. Those activities are steel column installation and roof-truss installation.

Analysis and Discussion

6.2.5.4 Time & Motion Analysis

Approach I: (Using construction method No.1 and construction machine set No.1)

The construction planning by “*Approach I*” in this case study can adapt the construction methods and construction machine sets from the earlier example case (See

example *Case II: Time-motion study of steel column and roof-truss installation*). The construction method and construction machine sets in this approach can be illustrated by using the virtual reality scene in Figure 6.7

During construction, planners use the virtual reality approach to analyze the construction method. The results of this analysis can present some conflicts and problems of construction as follows:

- 1) Both truck-cranes can install only four columns at a time in their line since installation of more than four steel columns at a time will obstruct the carriage of roof-trusses by the excavator.
- 2) Maximum boom length of the mobile-crane is limited.
- 3) Both truck-cranes have to wait until the four roof-trusses are already installed before they can start to install the next column again.
- 4) Operation paths of the excavator are too long to carry and move roof-trusses.

Approach I: Using construction method No.2 and construction machine set No.1

In order to reduce conflicts and problems of the construction method in *Approach I*, the construction method should be changed, and the productivity of the construction machines should be improved. When the planners look at the virtual reality scene as shown in Figure 6.9, they can see the obvious problem that the operation paths of the excavator are too long. Thus, the construction method should be improved by changing the starting location of roof-truss installation. Roof-truss installation should be started at the middle of the factory building in order to reduce the length of the excavator path used to carry and move roof-trusses as shown in Figure 6.10.

It is concluded that changing the construction method can improve construction machine productivity. It can reduce the operation time of every construction machine used to install steel-columns and roof-trusses of factory building. The results of construction time improvement are shown in Table 6.3

Table 6.3: Results of operation time improvement by using *Approach II*

Construction Method	Activities		Operation Time of Construction Machine Set No. 1 (min.)			
	Install Column	Install Truss	Mobile-Crane No.1	Excavator No.1	Truck-Crane No. 1	Truck-Crane No. 2
1	32	16	1,393	1,226	1,010	1,031
2	32	16	1,371	1,071	819	840

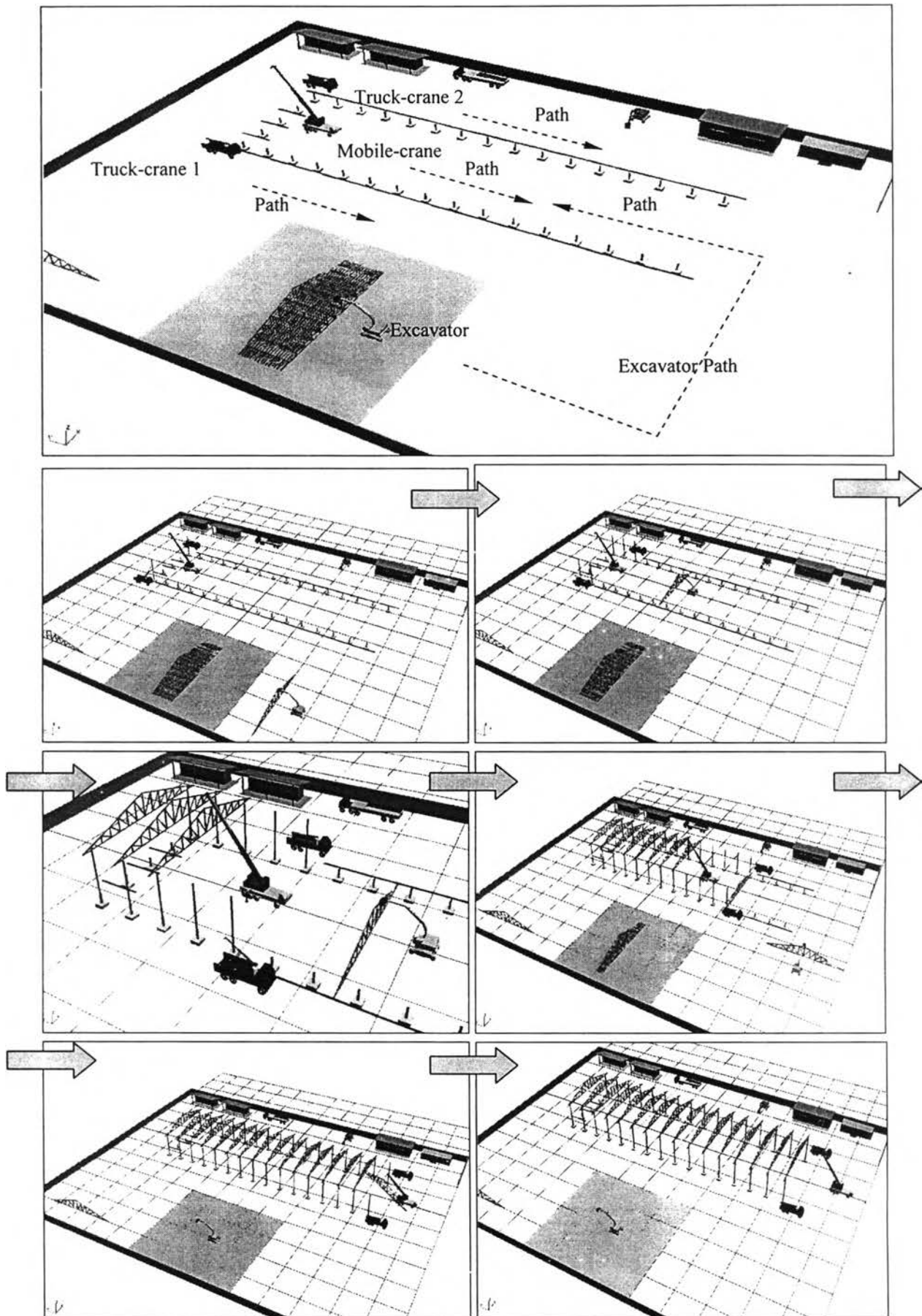


Figure 6.9: Time-motion of construction-machines set No.1 by construction method No.1

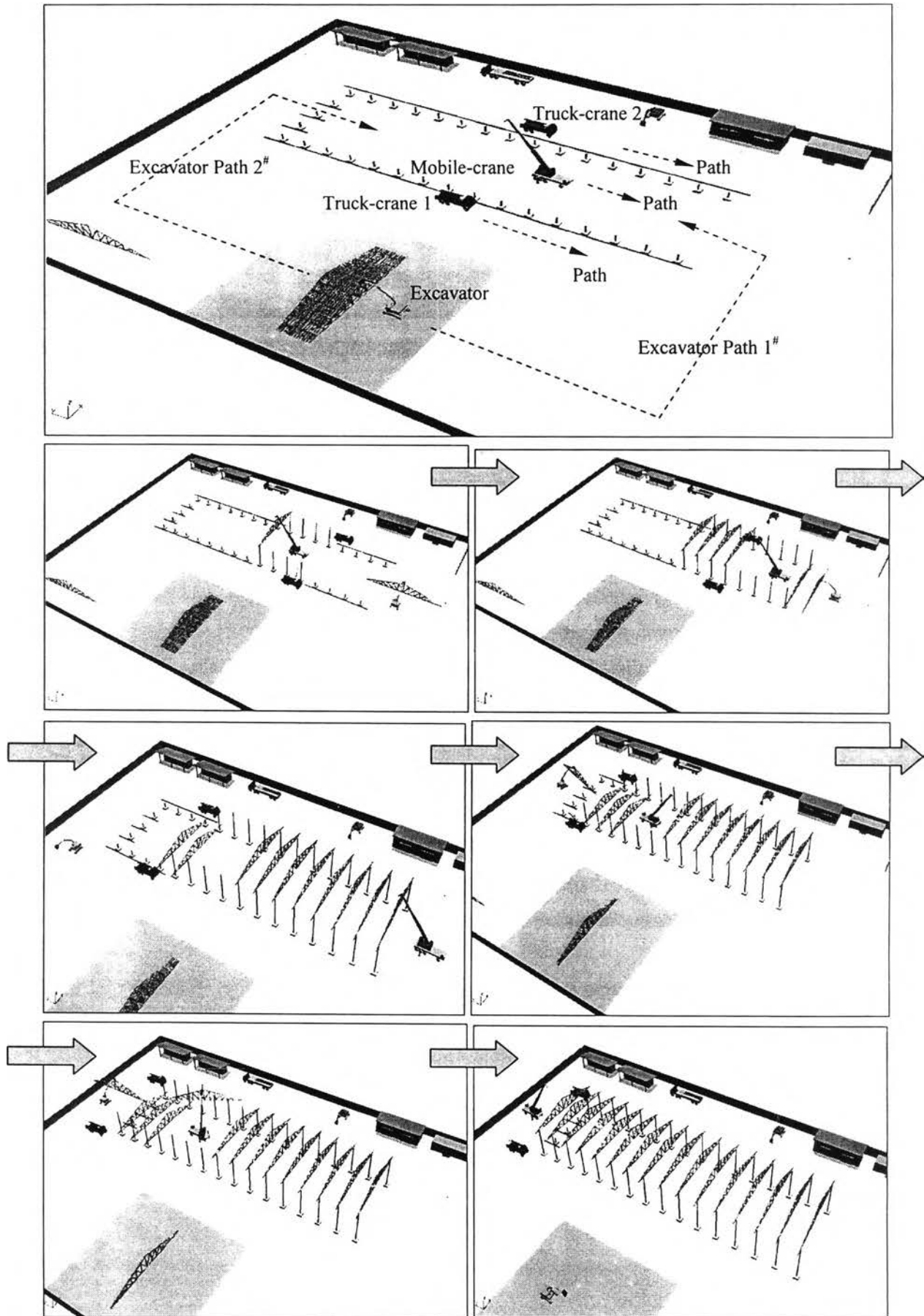


Figure 6.10: Time-motion of construction machines set No.1 by construction method No.2

Approach III : Using construction method No.3 and construction machine set No.2

Although the construction method in *Approach II* is improved, however, it cannot eradicate all of the conflicts and problems. In *Approach II*, both truck-cranes can still install only four columns at a time in their line since the following conflicts and problems still occur: 1) steel-columns that are installed more than four columns at a time still obstruct the carriage of roof-trusses by the excavator, and 2) the maximum boom length of the mobile-crane is still limited. Therefore, those truck-cranes have to wait until the four roof-trusses are already installed before they can start to install the next column.

In order to eradicate those problems, the construction method should be further modified again. The construction method and construction machine set should be changed as follows:

1) The method of roof-truss installation by the mobile-crane should be changed by moving the positions of the mobile-crane. The mobile-crane should be relocated to the side of the building instead of the middle of the building. Thus, excavator can continuously carry and move roof-trusses without the obstacles of column installation.

2) Both truck-cranes can carry and install steel columns without the obstacle of roof-trusses moved by the excavator. Consequently, those truck-cranes can install the steel columns continuously without waiting time.

3) Larger mobile-cranes are used to install roof-trusses instead of the previously utilized small mobile-cranes. Its boom length is long enough to lift and swing roof-trusses from the side of the factory building. Therefore, this mobile-crane can continuously install roof-trusses without waiting time. (See Figure 6.11)

By this approach, project planners can eradicate most of the conflicts and problems that occur in *Approach I* and *Approach II*, since all of construction machines can be operated without any waiting time. Thus, all activity durations can be shortened and the project planners can reduce the construction project time as show in Table 6.4.

Table 6.4: Results of operation time improvement by *Approach III*

Construction Method	Activities		Operation Time of Construction Machine Set No.2 (min.)			
	Install Column	Install Truss	Mobile-Crane No.2	Excavator No.1	Truck-Crane No. 1	Truck-Crane No. 2
3	32	16	1305	730	439	486

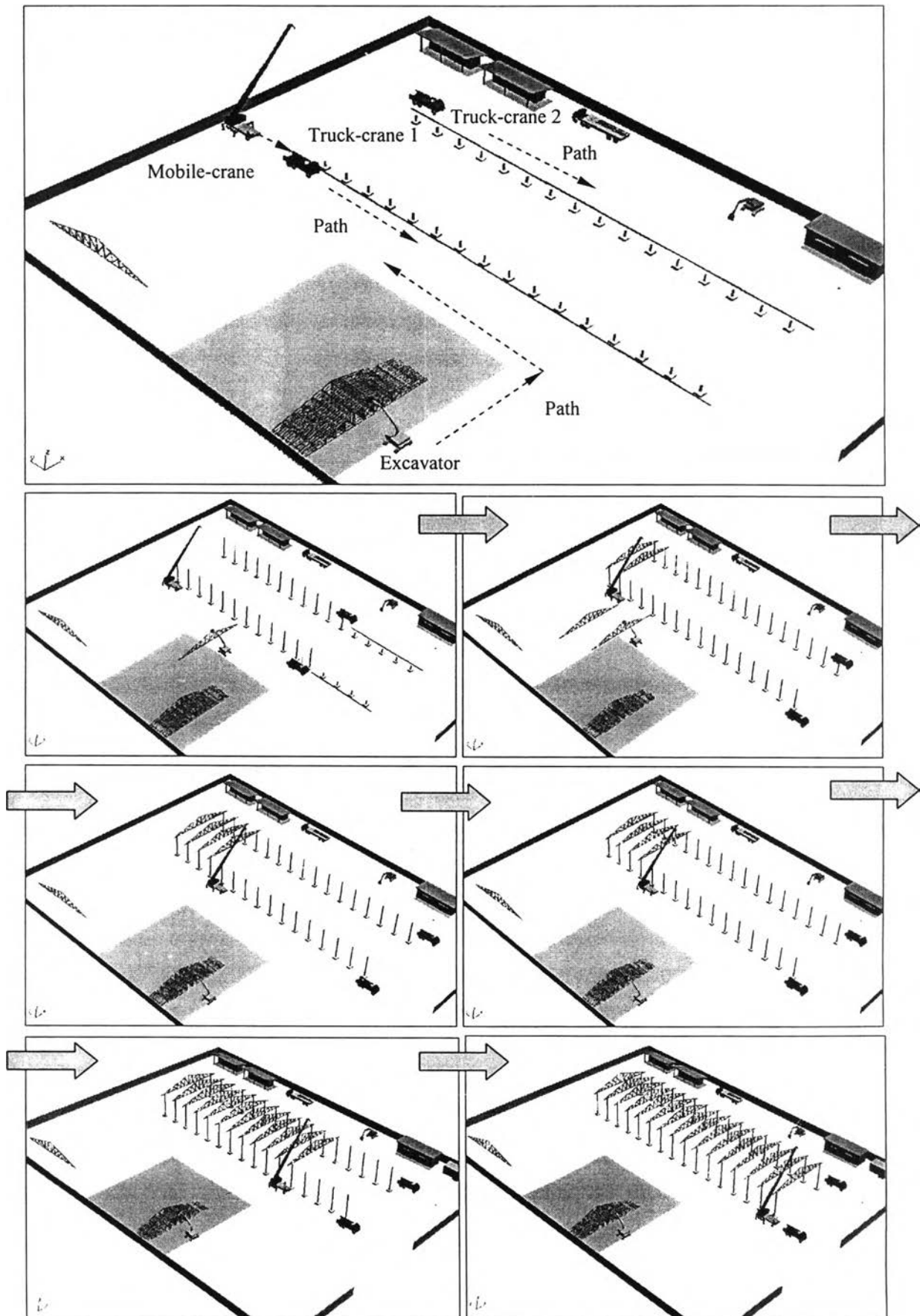


Figure 6.11: Time-motion of construction-machines set No.2
by construction method No.3

6.2.5.5 Time - Cost Analysis

In this case, the operation cost of factory construction consists of: 1) the cost of construction machines (rent), 2) the cost of craftsmen and labor, and 3) the site office overhead. It is assumed that the construction activities (steel column and roof truss installation) in each approach use the same craftsmen and labor gang. Thus, operation cost consists of only the construction machine cost and site-office overhead.

Both the construction machine cost and site office overhead depend on operation time. When the operation time of construction activities is calculated in each approach, the operation cost can be calculated by multiplying unit the price of the construction machine and site-office overhead with operation time as follows:

$$\text{Total operation cost} = \sum (Tm_i * UP_i) + Tt * SOH \dots \dots \dots (1)$$

- When Tm_i = Total operation time of construction machine (i)
 UP_i = Unit price of construction machine (i) (See Table 6.9)
 Tt = Total operation time
 SOH = Unit price of site-office overhead (See Table 6.9)

According to time-motion analysis using the virtual reality approach, the results of time-cost analysis are described in Table 6.5 – Table 6.8.

In Table 6.5 and Table 6.6, it can be summarized that the total operation time of the construction machines in *Approach I, II and III* are 1518, 1421 and 1305 minutes, respectively. The total operation time in *Approach III* is lowest. When planners consider the operation time of each construction machine type, it is evident that the operation time in *Approach III* is shorter than that of *Approach II* and the operation time in *Approach II* is shorter than that of *Approach I*.

However, when operation the cost in Table 6.7 is calculated by using the unit price of the construction machines and site office overhead in Table 6.9, the total operation cost of construction activities in *Approach II* is the lowest. The total operation cost in *Approach III* is lower than that of *Approach I* but it is higher than that of *Approach II*. Since the operation time in *Approach I* is longest, that approach will generate the highest operation cost. Also, the unit price of the large mobile-crane in *Approach III* is high (12,000 Baht per day) so it also generates a high operation cost.

Unit price negotiation

If the unit price of the large mobile-crane is negotiated and decreased from 12,000 baht per day to 9,000 baht per day when the mobile-crane is rented for more than three days, as shown in Table 6.10, the operation cost of the large mobile-crane will be decreased. The total operation cost in *Approach III* is the lowest as shown in Table 6.8.

Table 6.5: Result of time-cost analysis (Construction Method 1 & 2 and Construction machine set 1)

Construction Method	Material	Quantity	Operation Time of Construction Machine Set 1 (Min.)				Operation Cost of Construction Machine Set 1 (Baht)				Total Operation Time (Min.)	Total cost of Machine-Operation (Baht)
			Mobile Crane No.1	Excavator No.1	Truck Crane No.1	Truck Crane No.2	Mobile Crane No.1	Excavator No.1	Truck Crane No.1	Truck Crane No.2		
1	32	16	1,393	1,226	1,010	1,031	16,252	15,325	8,417	8,592	1,518	48,585
2	32	16	1,371	1,071	819	840	15,995	13,388	6,825	7,000	1,421	43,208

Table 6.6: Result of time-cost analysis (Construction Method No.3 and Equip. set No.2)

Construction Method	Material	Quantity	Operation Time of Construction Machine Set 2 (Min.)				Operation Cost of Construction Machine Set 2 (Baht)				Total Operation Time (Min.)	Total cost of Machine-Operation (Baht)
			Mobile Crane No.2	Excavator No.1	Truck Crane No.1	Truck Crane No.2	Mobile Crane No.2	Excavator No.1	Truck Crane No.1	Truck Crane No.2		
3	32	16	1305	730	439	486	27,188	9,125	3,658	4,050	1,305	49,458

Table 6.7: Results of time-motion-cost analysis

Construction Method	Material Quantity		Equipment set No.1 Work Time (Min.)				Equipment set No.2 Work Time (Min.)				Total Work Time (Min.)	Equip. Cost (Min.)	Total Cost (Baht)
	Column	Truss	Mobile Crane No.1	Excavator No.1	Truck Crane No.1	Truck Crane No.2	Mobile Crane No.2	Excavator No.1	Truck Crane No.1	Truck Crane No.1			
1	32	16	1393	1226	1010	1031					1,518	48,585	64,398
2***	32	16	1371	1071	819	840					1,421	43,208	58,010
3	32	16					1305	730	439	486	1,305	49,458	63,052

Table 6.8: Results of time-motion-cost analysis after negotiation

Construction Method	Material Quantity		Equipment set No.1 Work Time (Min.)				Equipment set No.2 Work Time (Min.)				Total Work Time (Min.)	Equip. Cost (Min.)	Total Cost (Baht)
	Column	Truss	Mobile Crane No.1	Excavator No.1	Truck Crane No.1	Truck Crane No.2	Mobile Crane No.2	Excavator No.1	Truck Crane No.1	Truck Crane No.1			
1	32	16	1393	1226	1010	1031					1,518	48,585	64,398
2	32	16	1371	1071	819	840					1,421	43,208	58,010
3***	32	16					1305	730	439	486	1,305	38,583	52,177

Remark: sign “***” refers to an appropriate approach.

Table 6.9: Unit price of construction machine and site office overhead.

Construction Machine	Type & Size	Price	Unit
Mobile Crane	No.1	5,600	Baht/day
Mobile Crane	No.2	12,000	Baht/day
Excavator	No1	6,000	Baht/day
Truck Crane	No.1	4,000	Baht/day
Truck Crane	No.2	4,000	Baht/day
Site office overhead		5,000	Baht/day

Table 6.10: Unit price of construction machine and site office overhead after negotiation

Construction Machine	Type & Size	Price	Unit
Mobile Crane	No.1	5,600	Baht/day
Mobile Crane	No.2	8,000	Baht/day
Excavator	No1	6,000	Baht/day
Truck Crane	No.1	4,000	Baht/day
Truck Crane	No.2	4,000	Baht/day
Site office overhead		5,000	Baht/day

Therefore, it can be summarized that the appropriate construction method and machine set in this case are those utilized in *Approach III* instead of *Approach II*.

6.3 Application of Integrated System for Construction Site-Layout

In general, project managers or project planners may utilize 2D drawings to assign construction-site boundaries and to allocate facilities and resources. However, the limitation of the 2D approach is that it is difficult to visualize the construction site in all dimensions, and thus difficult to identify the complicated problems. Thus, the 3D or virtual reality approach is the interesting approach that can be applied for construction site-layout operations. The 3D CAD models of facilities and resources created in AutoCAD in true scale can be imported into the 3D visualizer, which can be used as an animator or visualizer to display the visualized construction site. The planners can move or change the position of the 3D models to determine appropriate position of those

facilities and resources within the limitations of the construction-site boundaries in order to create a more realistic construction-site layout.

6.3.1 Site-layout Descriptions, Importance and Problems

6.3.1.1 Descriptions

Site-layout consists of identifying the facilities and resources needed to support construction site operations, determining their sizes and shapes, and also locating their positions within the site boundaries. Facilities allocation on site is a routine but not an easy task (Tommelein et al., 1992)

Site-layout planning involves identifying, sizing and locating the necessary temporary facilities on the construction site. Temporary facilities range from simple lay-down areas to warehouses, fabrication shops, maintenance shops, batch planes and residence facilities.

6.3.1.2 Importance

Site space is a resource that is as important as money, time, material, labor and equipment. Although it is important, site planning is often neglected and the engineer's attitude has been that it will be done as the project progresses. (Hegazy and Elbeltagi, 1999). Good site-layout is important for promoting safe and efficient operation, minimizing travel time, decreasing material handling and avoiding obstructing material and equipment movement (Tommelein et al., 1992)

Assigning space before construction starts can prevent unnecessary material handling, minimize travel time, and avoid congestion. Moreover, temporary facilities can be more thoughtfully designed and their uses coordinated if the needs are assessed for the project overall (Tommelein and Zouein, 1993).

6.3.1.3 Problems

The allocation of temporary facilities to space on site is a routine, but not easy construction management task. There are many factors that affect an achievement of site-layout. Many people are involved in realizing or changing the layout in the field (Tommelein et al, 1992). Space and site-layout is difficult to model and the payoffs from modeling are not readily apparent (Tommelein and Zouein, 1993).

Tommelein and Zouein (1993) has presented several problems involve site-layout modeling:

- 1) It is difficult to represent space, since human thinking is more abstract graphically depicted. Thus, in the past, drawings have been assisted to enforce a possibly inappropriate spatial representation.

- 2) It is difficult to determine the space required for conducting construction operation and those needed for resources such as material and equipment. Allocating space is more difficult than allocating other resources, for which there are no optimal

algorithms to start with. Spatial variables are three-dimensional. On the other hand, time and cost are scalar. The total amount of space on site, as well as the location, shape and accessibility of space are important.

3) It is difficult to assign the value of space to accommodate a resource due to complexities of computing, tracking, representing and updating data during planning.

6.3.2 Existing Tools for Site-Layout

WALKTHRU

A construction sequencing tool called “WALKTHRU” is based on computer-aided design or drafting (CAD) packages. It can capture the static figures and simulate the construction progress by playing back those captured figures. It allows users to walk through and look at the construction details. It is suitable for modeling construction operation such as locating the position of expensive equipment and monitoring the construction process.

SightPlan

Tommelein and Zouein (1993) used expert-time strategy to develop a layout tool called “SightPlan” It can create layouts over the duration of construction project by locating given temporary facilities to their period which are on site. It places one facility at a time through a constraint satisfaction search.

MovePlan Model

MovePlan Model was developed by Tommelein et al. (1992). It has been used as a decision-support tool to establish dynamic layouts. Users can apply MovePlan to plan the positioning and movement of resources on site for discrete time intervals. It can not only support users by identifying resources on site for a given time period, but also underlying consistency maintenance mechanisms enforce that only consistent layouts be generated.

6.3.3 The Disadvantages of Existing Layout Tools

The limitations and disadvantages of existing layout tools are listed in Table 6.11

Table 6.11: Disadvantages of Existing Layout Tools

No.	Layout Tools	Limitations and Disadvantages
1	WALKTHRU	1) Inadequate for modeling space during early planning because insufficient details about project components and selected resource 2) Unable to model an entire project as their demand for details
2	SightPlan	1) There is no mention of schedule-layout integration in SightPlan 2) Presented in 2D approach
3	MovePlan	1) Presented in 2D approach

6.3.4 Applying Integrated System for Site-Layout

6.3.4.1 Application Motive

The main limitation of a 2D approach is that it is difficult to visualize the construction site in all dimensions, and thus to visualize the complicated problems that can arise. Thus, 3D or virtual reality approach is a promising approach for application on construction site layout. The AutoCAD was used to create the 3D CAD models of facilities and resources in true scale. Those 3D models can be imported into the 3D Visualizer, which can be used as an animator or visualizer to display the visualized construction operation.

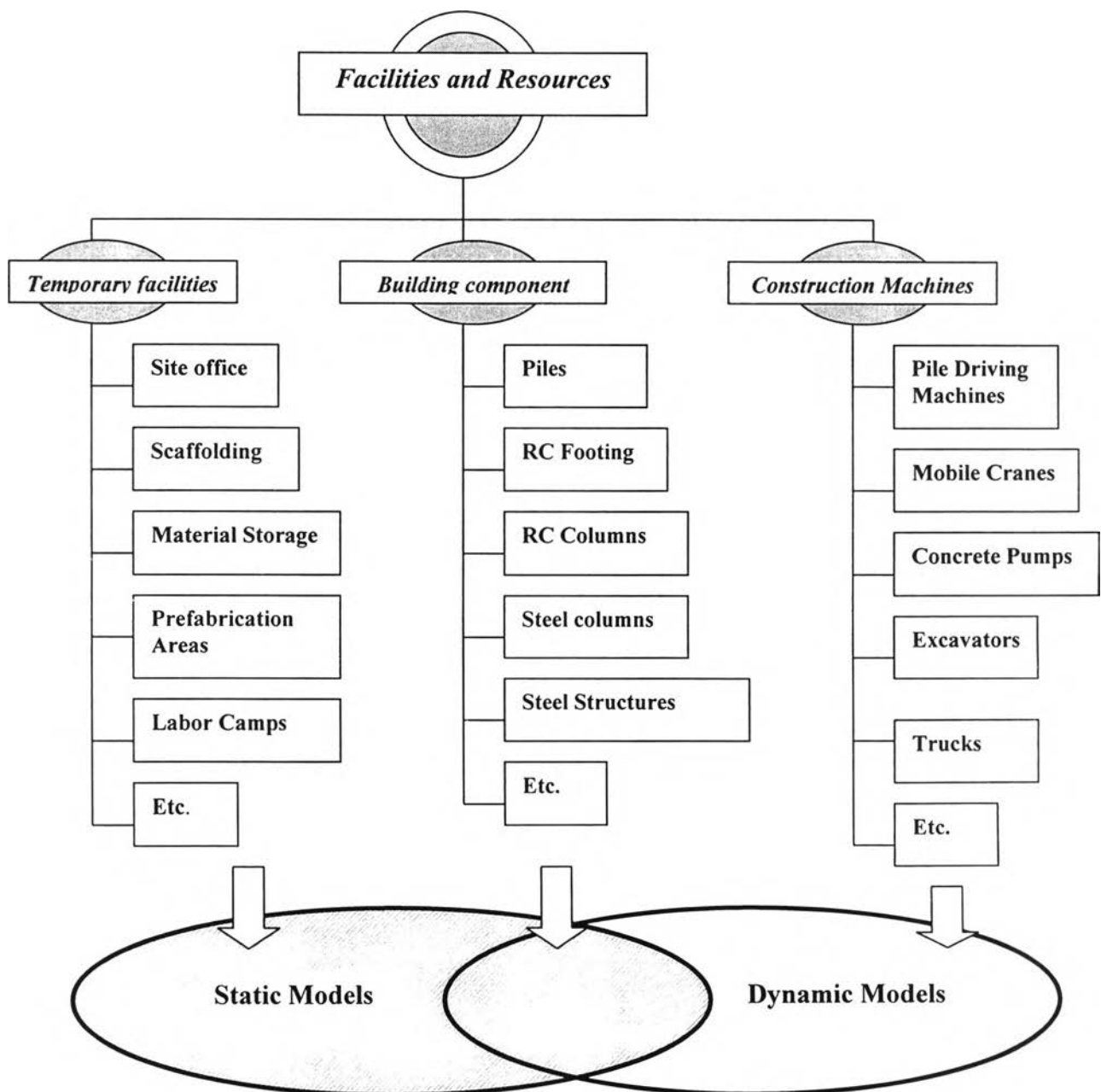


Figure 6.12: Facilities and resources classification

6.3.4.2 Classifying Facilities and Resources

According to Chapter 5, the facilities and resources for site layout can be classified into 3 types as follows: 1) temporary facilities, 2) permanent materials of building components, and 3) construction machines (See Figure 6.12). Temporary facilities refer to facilities on a construction site that can be removed or demolished after the construction project or construction activities are completed; e.g., site offices, scaffolding, material storage areas, maintenance and service areas, prefabrication areas, and labor camps.

Permanent materials refer to installed materials of the building components. These include piles, RC footings, RC columns, steel columns, roof structures, walls, and ceilings. Construction equipment refers to the main equipment or machines that their sizes are large enough to affect productivity of the construction operation.

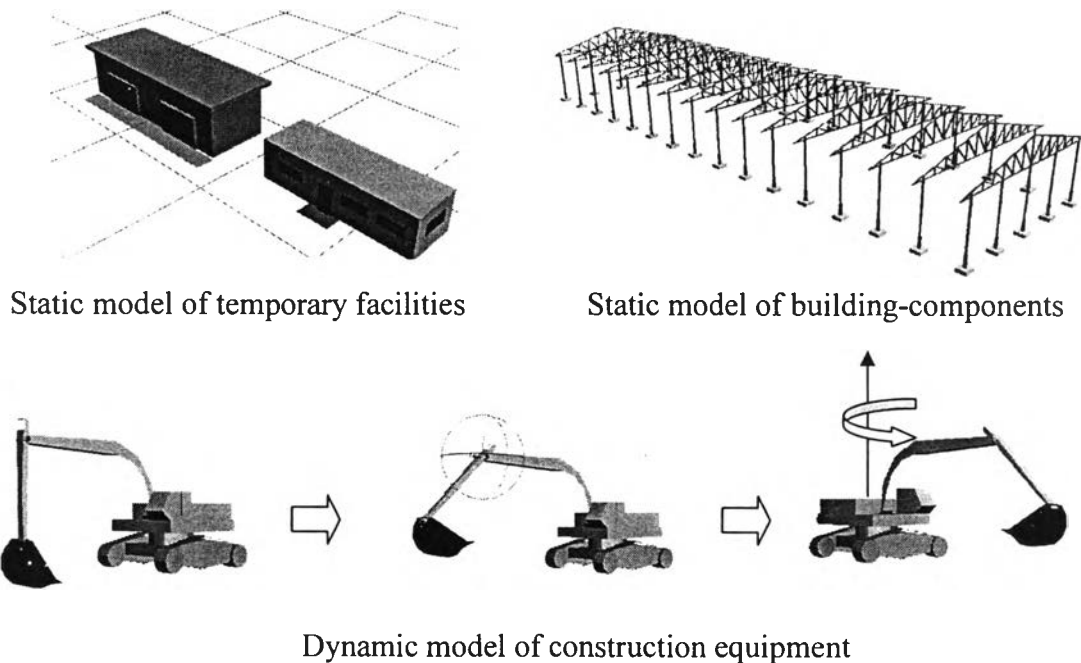


Figure 6.13: The static and dynamic models used in construction site-layout.

6.3.4.3 Facility and Resource Modeling

The 3D models of facilities and resources are classified by their shape transformation into 2 categories: 1) static models and 2) dynamic models. Static models are the 3D models that their shapes can be transformed like a “solid model”. In contrast, dynamic models are 3D models that their shapes can be transformed like a “mechanical model”. Static models are generated by CAD software (AutoCAD) and directly transferred to visualizer software (3DS MAX) by using the “*import*” command. On the other hand, dynamic models are generated by the CAD software and then assigned their mechanisms by 3DS MAX command. The steps and methods for generating both of those

models were described in Chapter 5. According to Figure 6.12, temporary facilities are usually generated as static models, but construction machines are usually generated as dynamic models. Building component can be generated as either static models or dynamic models as shown in Figure 6.13.

6.3.4.4 Facilities and Resource Library

After the 3D models of the facilities and resource were generated by CAD software and their characteristics assigned by 3D Visualizer, they were recorded in the library of the Integrated System database that was developed and described in Chapter 5. Those models can be retrieved for site layout planning by defining their information (types, models, size, capacity, etc.), for example, excavator model CAT 330L, wheel-loader model CAT 914G, or site office model STANDARD.

6.3.4.5 Locating Sequence and process

For planning construction site-layout using Integrated System, the procedures of site-layout are processed by the following steps:

- 1) Creating construction site boundary in the 3D space of 3DS MAX by using information (size and dimension) from drawing plan.

- 2) Importing the 3D models of the construction facilities into 3D space.

- 3) Locating the imported models in the appropriate positions. A locating strategy is used to locate the construction facilities such as priority strategy or first-in-first-serve strategy.

- 4) Moving and rotating the 3D models of facilities within the boundaries of construction site until the planners are satisfied.

- 5) If the planners are unsatisfied, those facilities can be operated in two approaches. First, planners can locate those facilities in other positions in the 3D space of construction site. Second, planners can remove the facilities from the construction site and import new facilities. For example, models of the prefabrication area can be moved from the boundary of construction site because prefabrication can be performed outside the construction site.

- 6) The position of the construction facilities can be improved after the construction simulation has been started or while the building-components are being imported to the 3D space of construction site.

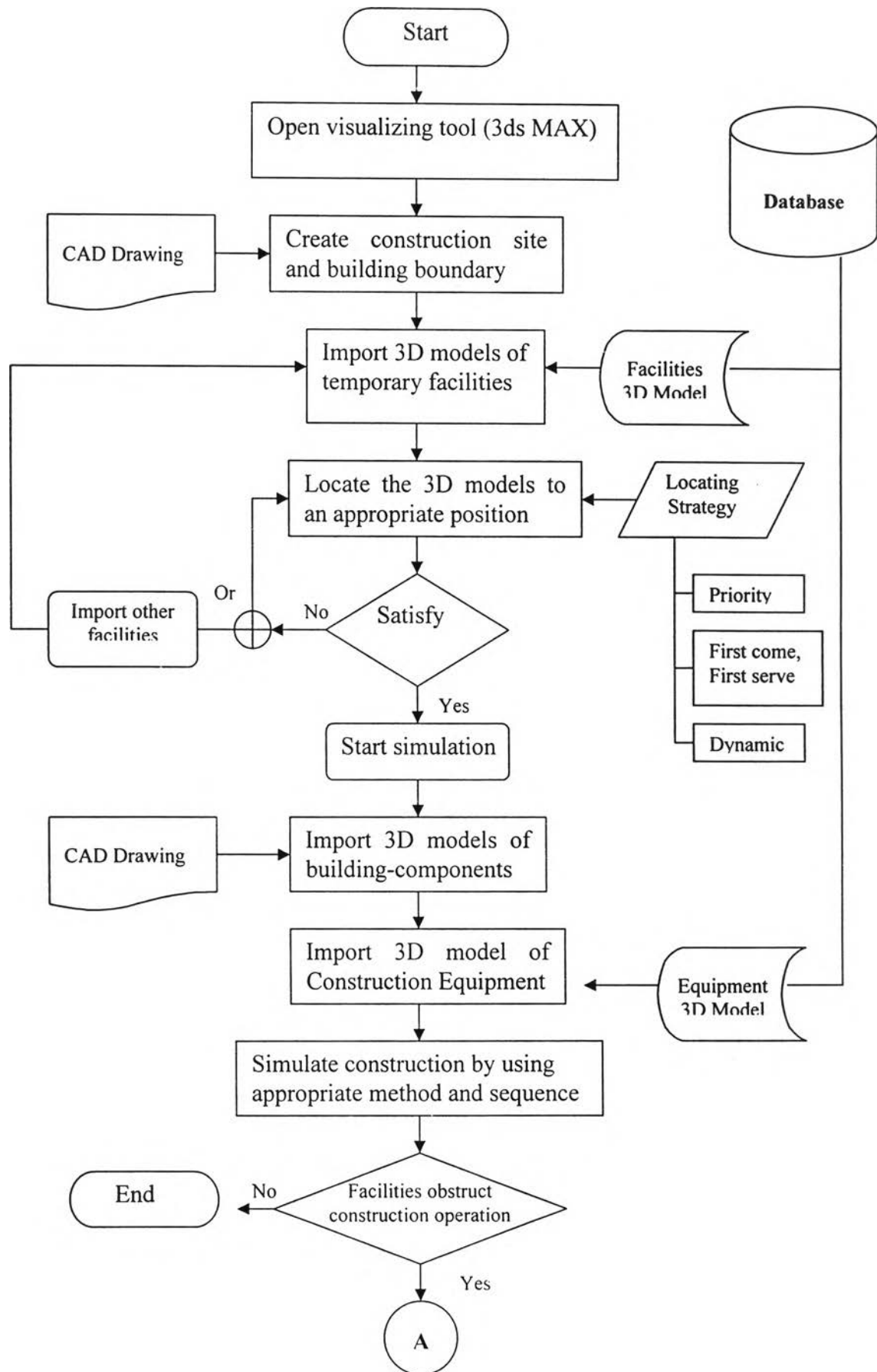


Figure 6.14: Flow chart of construction site-layout procedure

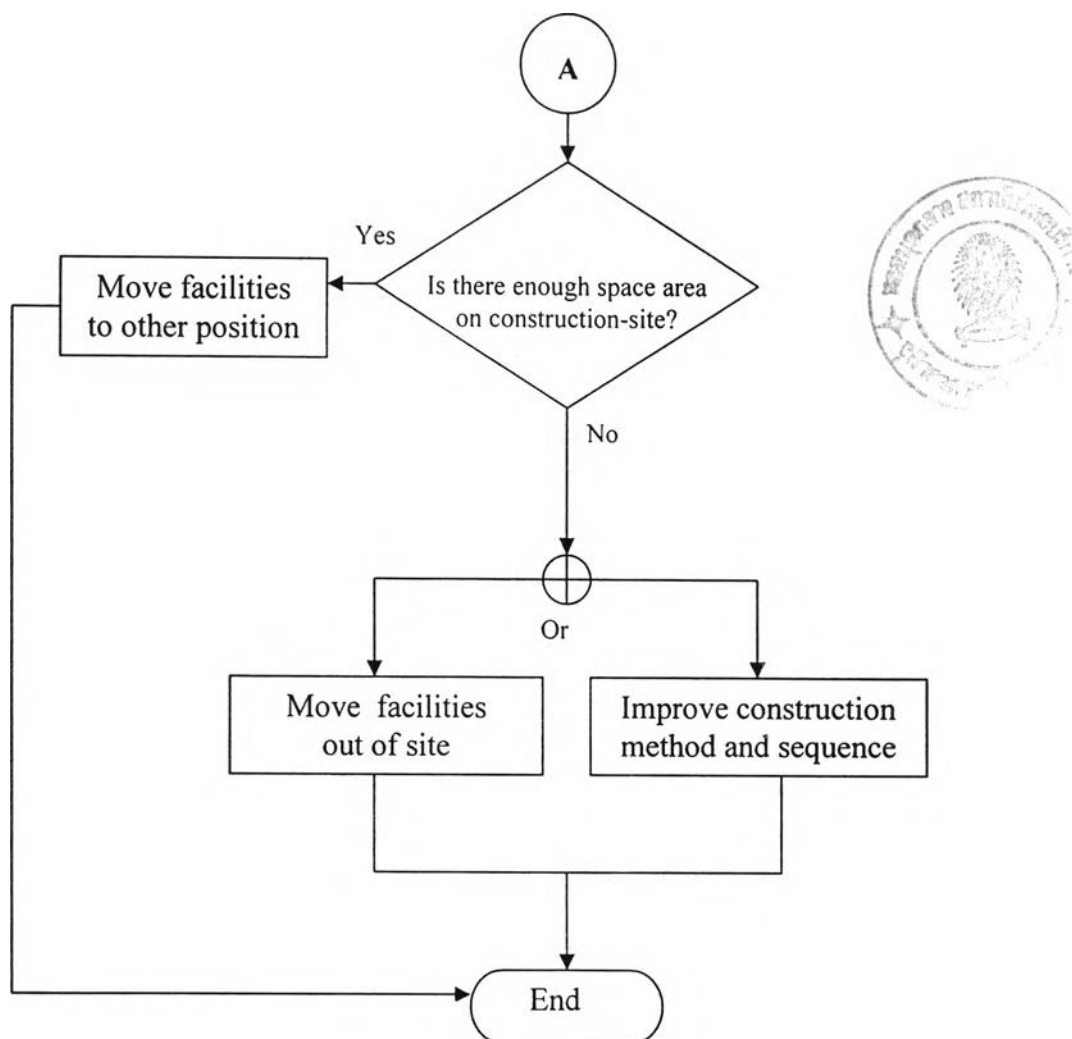


Figure 6.15: Flow chart of construction site-layout procedure (*Continue*)

7) If the construction facilities obstruct the building component installation or obstruct the paths of construction equipment operation, there are two approaches to solve the problem. The first approach is to move some facilities out of the construction site. The second approach is to improve the construction method and sequence by changing the types or sizes of construction equipment, changing the paths of equipment operation or changing the construction sequences.

All the steps involved in construction site layout management can be described by the flow chart of construction site-layout procedure in Figures 6.14 and 6.15. This procedure can be illustrated by the virtual reality approach in Figure 6.16

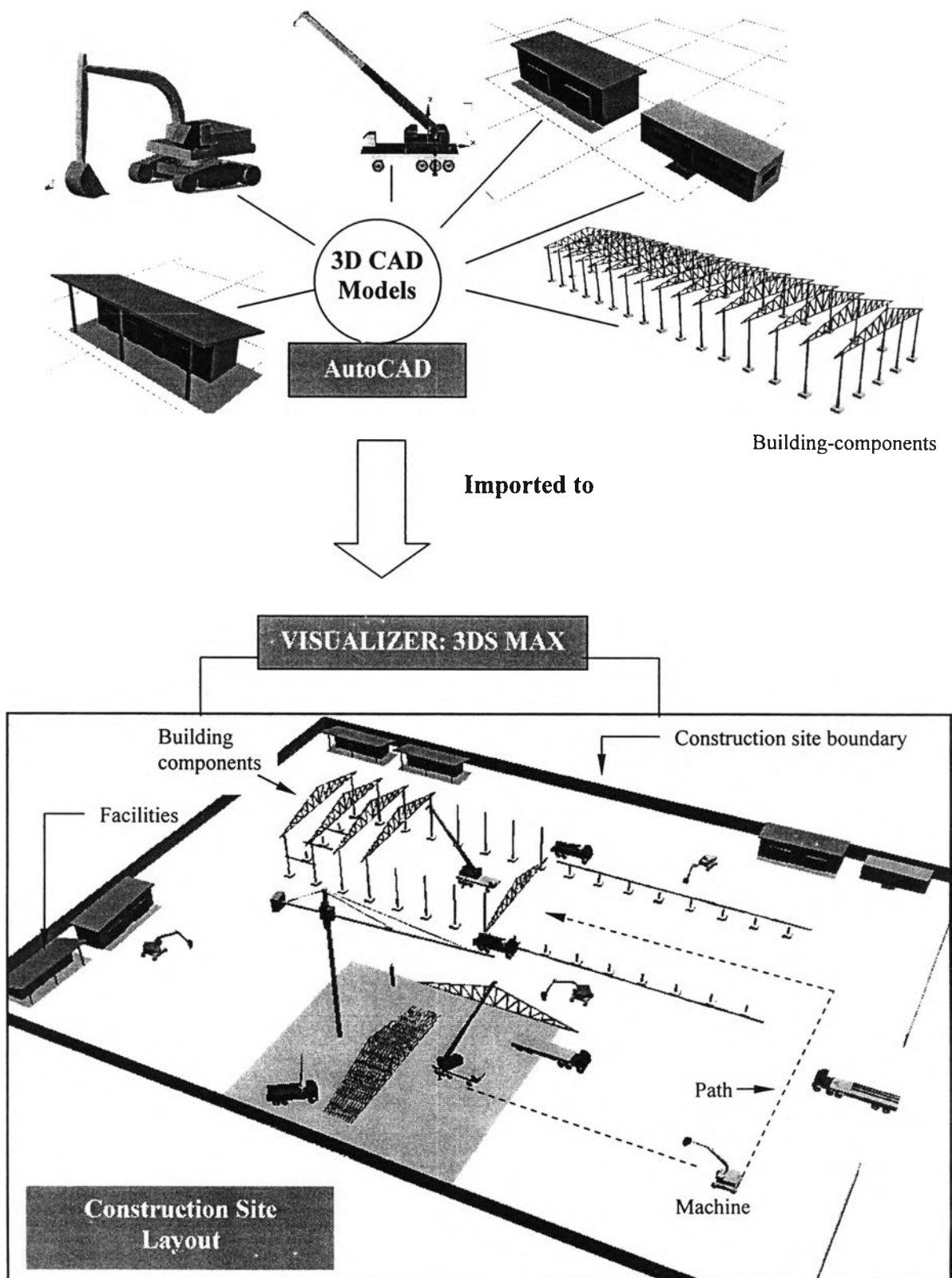


Figure 6.16: Construction site-layout processed by virtual reality approach

6.4 Application of Integrated System for Space Conflict and Safety Analysis

This chapter describes construction site management using the Integrated System involving construction space conflicts solution and safety analysis. Space-conflict definition and the existing workspace planning tools are presented, and space conflict solving procedures using the virtual reality approach in the Integrated System is described by using a flowchart. Additionally, four cases of study of space conflict and safety analysis are illustrated.

6.4.1 Space Conflict Identification

Construction space is hierarchically classified to illustrate its physical relationship to typical construction work. Construction operation normally requires space to operate construction work. Space conflict normally is a common problem found in construction sites. Construction planners need construction space models that can describe the types of construction spaces needed for construction work elements, as well as the spaces occupied by completed work units. In general, a construction space model defines two types of space:

- 1) Areas are spaces occupied by activity work elements for a period of time
- 2) Paths are spaces required for movement of material, equipment, and other resources (Riley and Sanvido, 1995).

Construction space conflict occurs frequently in construction sites due to the lack of a normal procedure or methodology to identify all potential space conflicts (Guo, 2002).

6.4.2 Existing Tools of Workspace Planning

(Guo 2002) applied two common tools, AutoCAD for space planning and MS-Project for scheduling, to analyze the space conflict problem. The CAD system was used to display the space planning results for various subcontractors. The system can suggest a revised or updated original schedule, according to the minimized delay caused by space conflicts by linking to MS-Project.

Akinci et al. (2002) developed a prototype system called “4D WorkPlanner Space Generator (4D SpaceGEN)”. This system can automate the generation of the workspace requirement of construction activities based on user-defined generic space requirement knowledge and project-specific production models.

6.4.3 Space-Conflict Solving Procedure Using an Integrated System

In this research, the Integrated System can be applied to analyze space and safety issue in a construction site due to the potential of the virtual reality approach which can display the construction site models in all dimensions (x, y, z, and time). Project

managers can walkthrough the virtual construction site to observe the conflict areas and dangerous events.

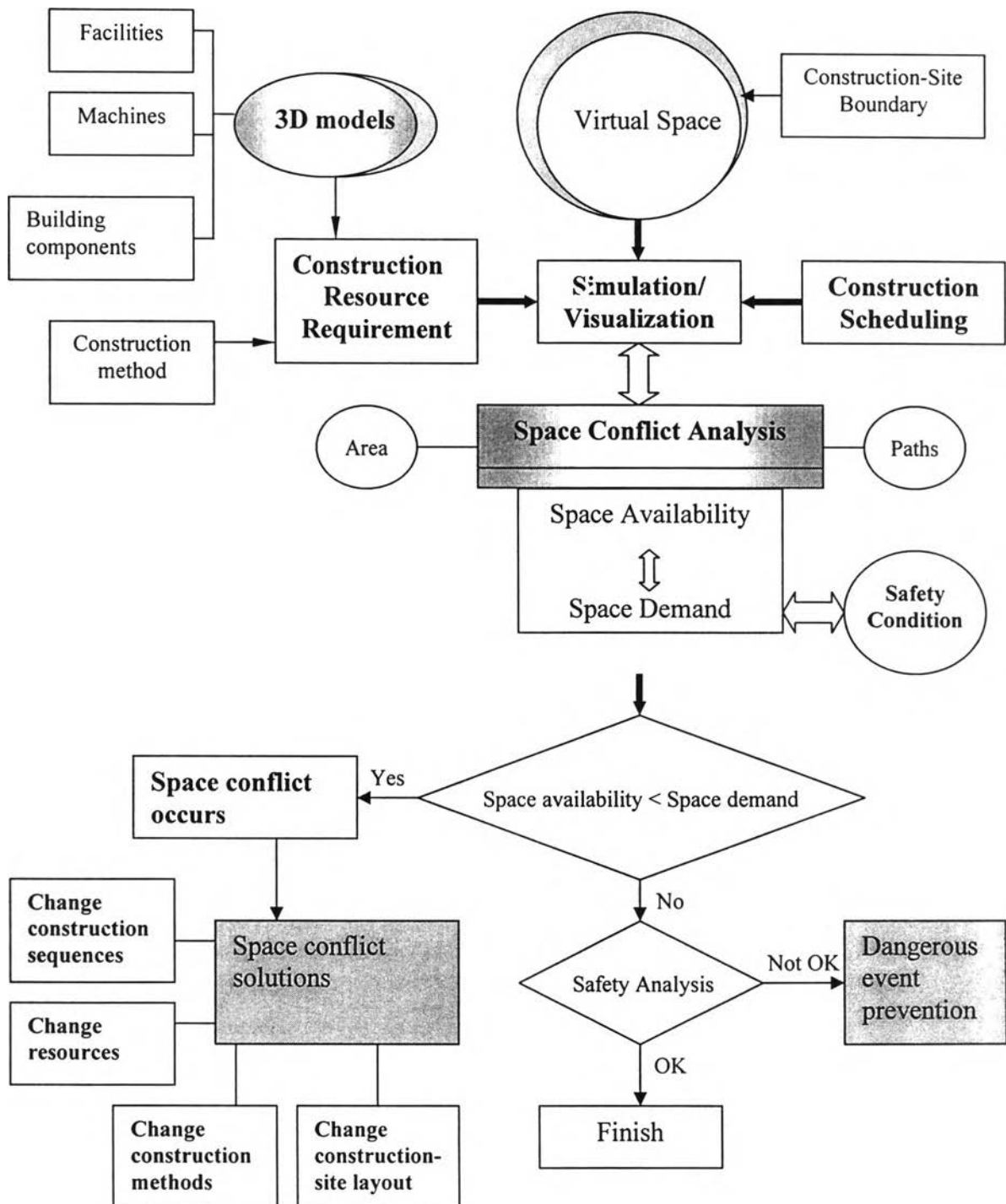


Figure 6.17: Flowchart of construction space conflict analysis.

The 3D models of construction resource requirements are imported to the virtual space of the construction site. These models are simulated and visualized according to preliminary construction methods and preliminary scheduling. During simulation, construction space demands and space availability are compared and experimented within the virtual space of the construction site boundaries. If space availability within construction-site boundaries is lower than the space demands of the construction resources, construction space conflicts will occur. Thus, project managers must solve these space conflict problems. Due to the advantages of virtual reality in the Integrated System, the project manager can observe and solve space conflicts effectively in all dimensions by changing construction operations as follows:

- 1) Changing construction methods
- 2) Changing construction sequences
- 3) Changing resources used
- 4) Changing construction-site layout

Moreover, project managers can investigate unforeseen problems and dangerous events in the virtual construction site and take preventative measures before these dangerous operations actually occur in real construction process.

The procedures of construction space conflict and safety analysis using a virtual reality approach are presented in the flowchart in Figure 6.17.

6.4.4 Case Study Illustration

Case I: Roof-trusses Installation by a mobile-crane operated inside of building

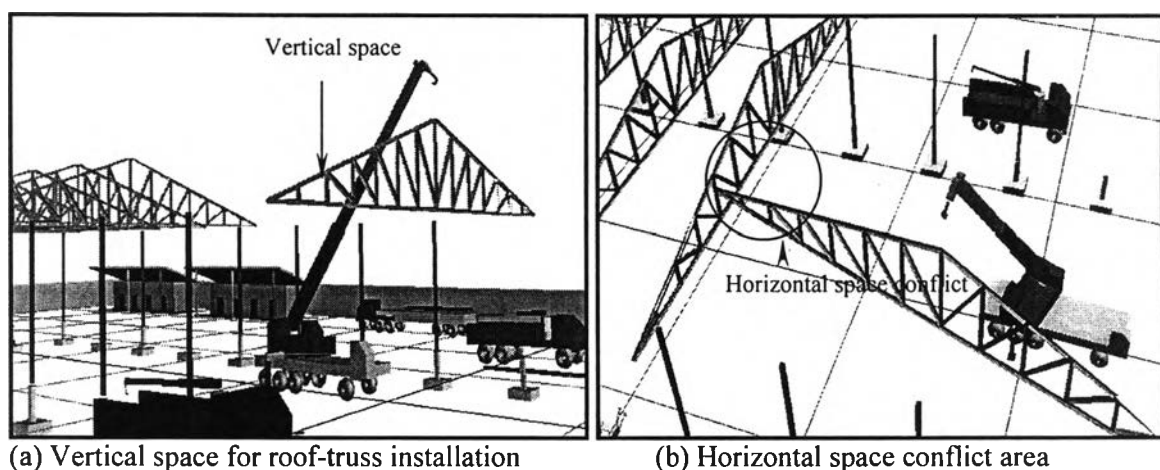


Figure 6.18 Space conflict and safety analysis for roof-structure installation by VR approach

In Figure 6.18 (a), the VR visualizer in the Integrated System can display that there is enough vertical space for roof-truss installation by the mobile crane. Figure 6.18 (b), however, shows that the horizontal space conflict occurs when the mobile crane swings

its arm to install a roof-truss, generating a dangerous event. Thus, the VR approach allow the project managers to perform extensive investigation to explore dangerous events and take precautions to ensure safety and prevent such dangerous event by changing the working methods and sequences of operation, or by selecting different sizes of equipment.

Case II: Tower-crane operations on construction site of multi-story factory

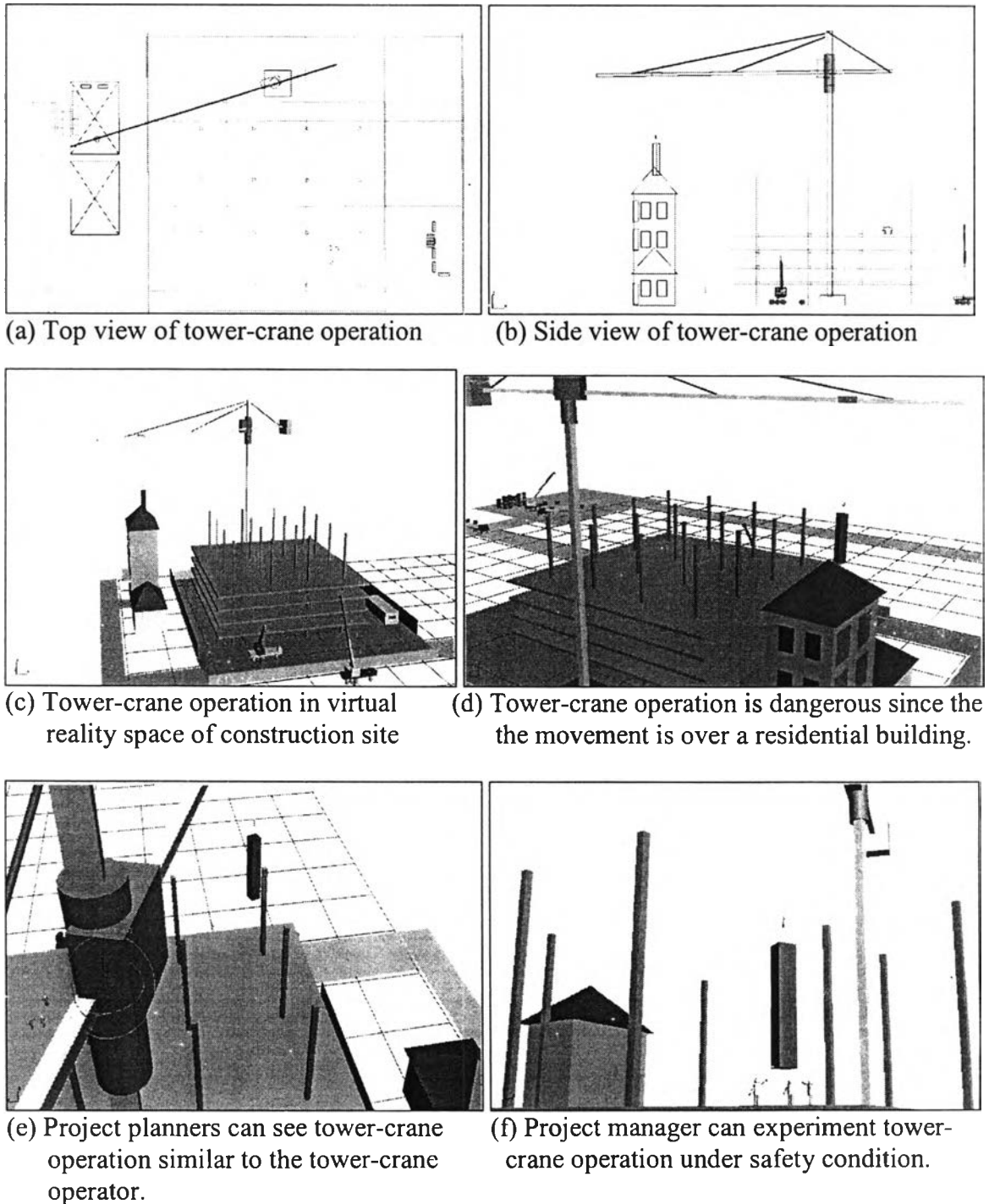


Figure 6.19: Space conflict and safety analysis of tower-crane operations.

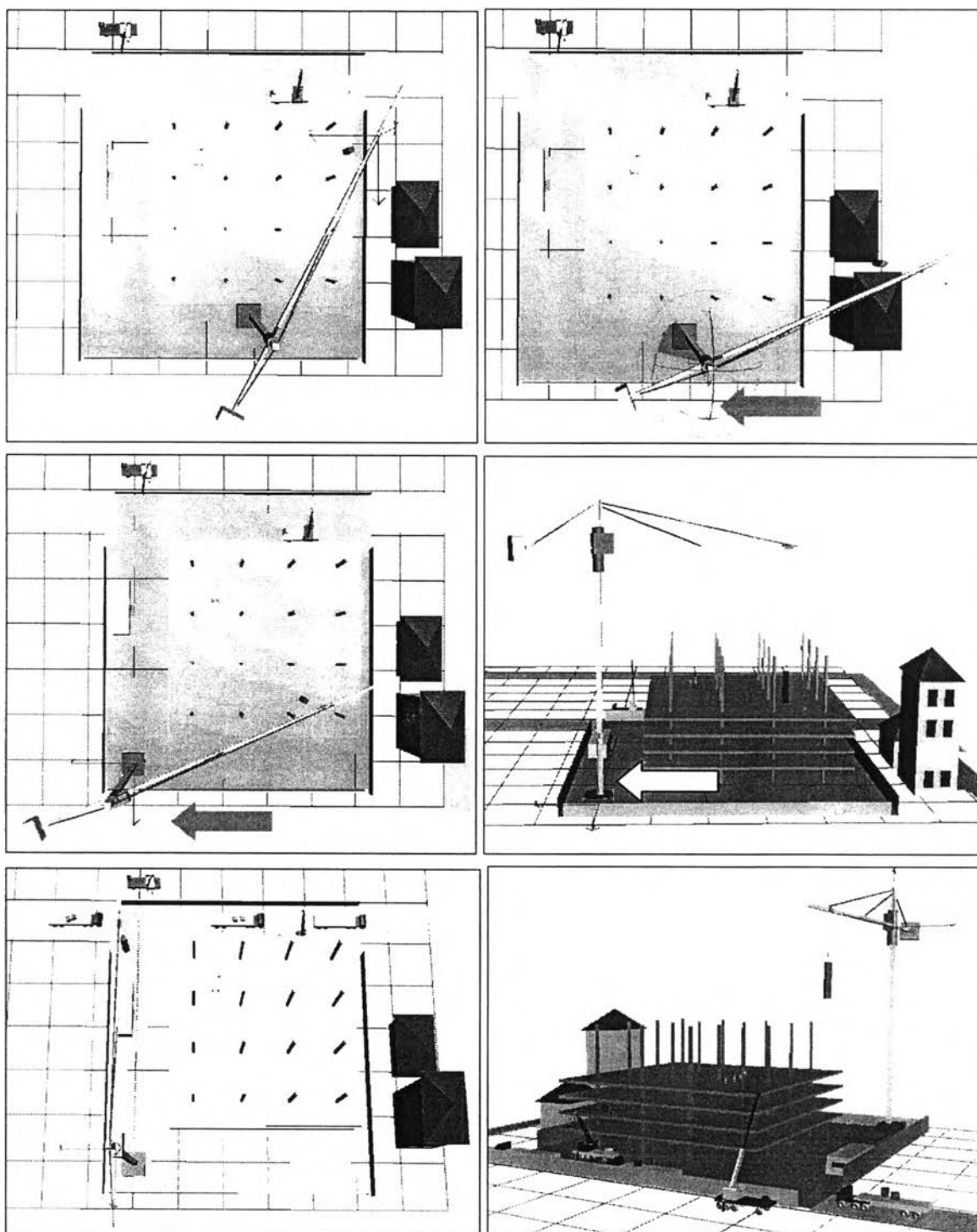


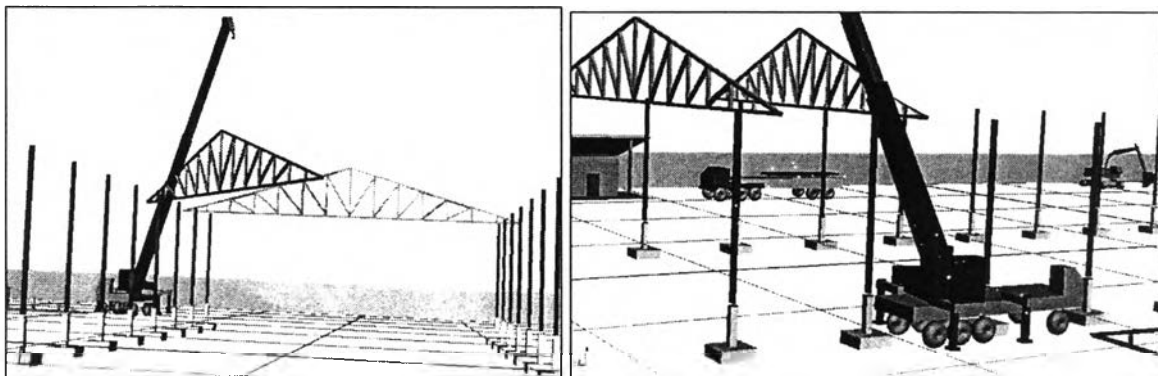
Figure 6.20: Moving the tower-crane location from dangerous operation point to safety operation position.

The project manager employs the virtual scene in the Integrated System to experiment with the operation of construction-machine such as the tower-crane. In Figure 6.19 (a) and 6.19 (b), tower-crane operation is presented in 2D form the top view and side view, respectively. Tower-crane operation is experimented with space-conflicts in the virtual space of the construction-site boundary (See Figure 6.19 (c)). In Figure 6.19 (d), the safety of the tower-crane operation is analyzed in virtual space. In Figure 6.20, tower-

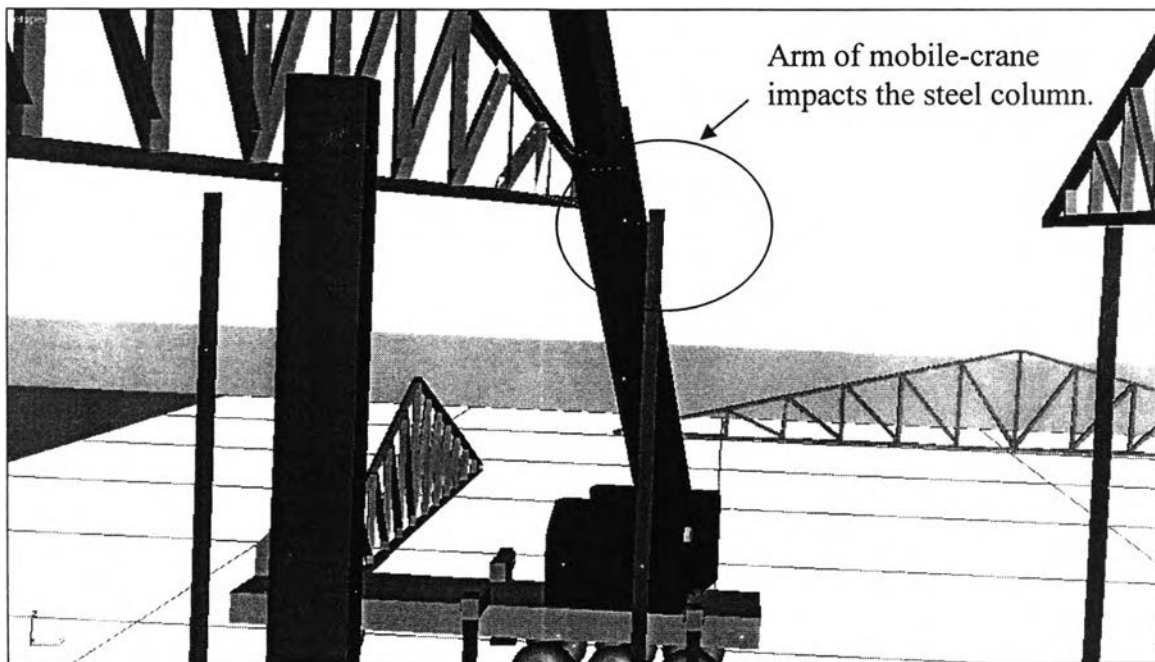
crane is moved from a dangerous operation point to a position where it can be operated under safety condition.

Case III: Roof-truss installation by a mobile-crane operating outside the building

Project managers can experiment construction-machine operation under different conditions using the virtual construction-site. In Figure 6.21, roof-trusses are installed by a mobile-crane operating beside the building. When project managers examine the mobile-crane operation in details, they can see that the arm or boom of the mobile-crane may impact a steel column because the mobile-crane is so close to the building. The project manager can now easily prevent the problem by changing the position or size of the mobile-crane.



(a) Mobile-crane is used to install trusses (b) Dangerous event occurs during installation

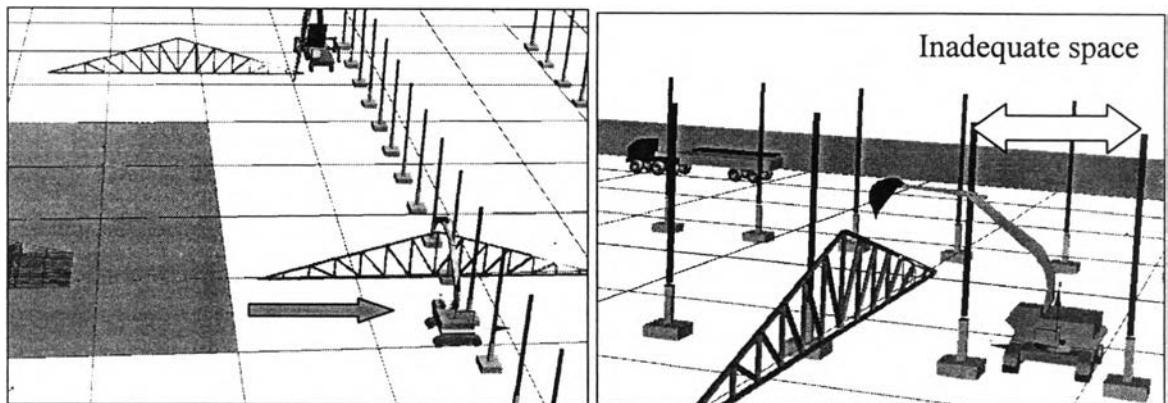


(c) Dangerous event is zoomed to look in detail

Figure 6.21: Dangerous event during roof-truss installation by a mobile-crane.

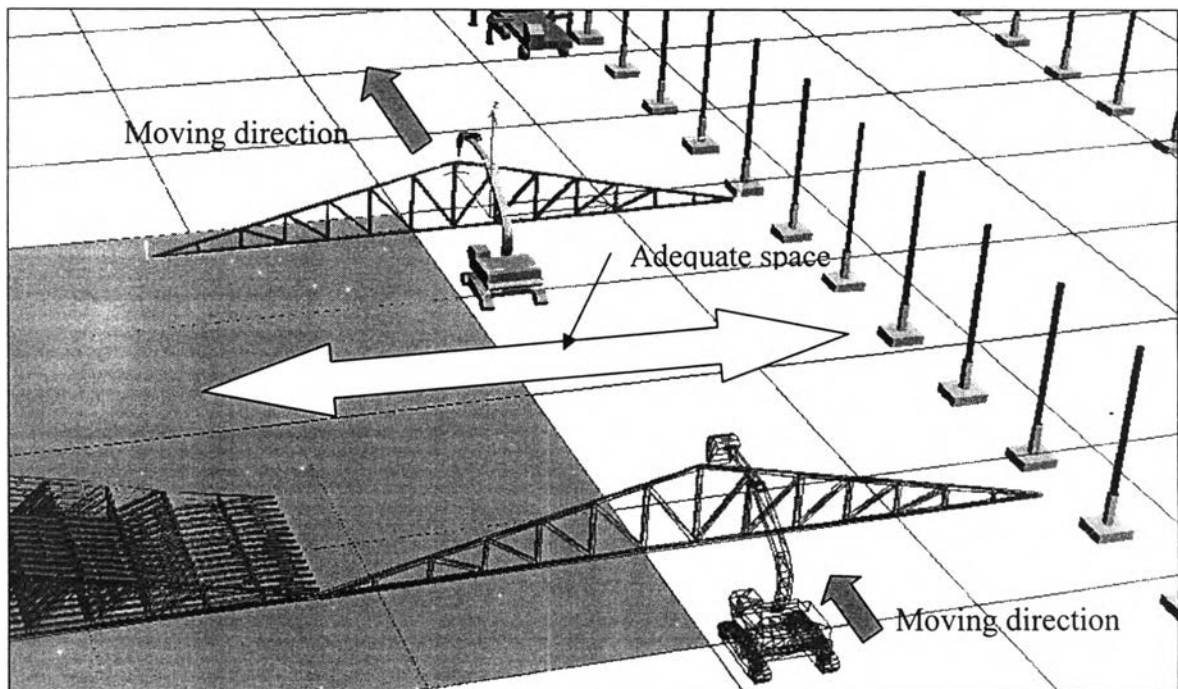
Case IV: Roof-trusses are carried and moved by an excavator

The project manager can use the Integrated System to analyze construction space. In Figure 6.22 (a), an excavator is used to carry and move roof-trusses that will be continuously installed by a mobile-crane. The excavator operation can be experimented with various conditions to determine the appropriate operation paths and analyze space conflicts. In Figure 6.22 (b), the excavator cannot move through building due to inadequate space. Thus, the operation path of the excavator is changed to a new path outside the building instead as shown in Figure 6.22 (c).



(a) Experiment for excavator operation

(b) Conflict of excavator moving due to inadequate space



(c) New path of excavator operation (moving outside the building)

Figure 6.22: Space analysis of roof-trusses carried by excavator in virtual construction site

6.5 Conclusion

This chapter illustrates the potential of the Integrated System, which is able to support integrated decision-making of construction planners in one main application and two by-product applications. Time-motion and cost analysis is the main application of the system. By-product applications involve construction space management that involves two applications: 1) construction-site layout, and 2) space conflict and safety analysis.

The Integrated System can be used to experiment with the different construction methods to generate different construction durations, and construction process cost in a virtual environment. Time-motion and cost of construction processes were analyzed by using what-if analysis in the system. The simple factory-building construction was selected as a case study. The proposed system can assist the construction manager to analyze and select the appropriate construction method, equipment set, operation time and cost of the construction process by visualizing the construction process in virtual space. The virtual reality approach can enhance the effectiveness of construction managers' decision-making by enabling them to visualize several dimensions of the virtual construction site generated in the Integrated System.

The first by-product application of the Integrated System development is construction site-layout using a virtual reality approach. Virtual reality is an effective approach for simulation in four dimensions (x, y, z, and time). The 3D CAD was used to create the 3D CAD models of facilities and resources in a scaled models. Those 3D models were imported into the 3D visualizer, which was used as an animator or visualizer to display the visualized construction site. The construction planners can move or change the positions of 3D models in order to determine the appropriate position of the facilities and resources within the limited boundaries to create a realistic construction site layout.

This chapter also describes construction space management using virtual reality approach in the Integrated System, which addresses construction space conflict solution and safety analysis. Space conflict solution using virtual reality approach in the Integrated System is described by a flowchart. In addition, four cases of study of space conflict and safety analysis are illustrated. The construction project planners can utilize the Integrated System to prevent construction space conflict and hazards before actual construction starts.