3-D Graphical Simulation for Crane Planning using Object-Oriented Building Product Model

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Abstract

Temporary Facilities are the most expensive resources at a construction site. In particular, the selection, positioning, planning and operation of a crane for a construction site control influences the overall construction planning and selection of the combination of construction methods. In Japan, at most construction sites around or inside the large city, crane operation is one of the big issues in determining the combination of construction methods because of the site constraint restrictions. Therefore, the utilization of a crane directly influences the constructability and productivity of its related construction operations. It is also important for a construction planner, or construction manager, to consider and to evaluate the construction work plans, and construction costs. This is so that they provide for the safety of the laborers, reducing construction costs, and maintaining the quality of the facilities. During the crane planning, any possible lack of equipment power and/or resource bottlenecks, should be identified.

On the other hand, an object-oriented product model is very powerful in describing each building element as an object, including its attributes for the crane simulation. Especially for the selection and positioning of the crane for a construction operation, the loading ability of the crane or interference between the elements and boom of the crane should be evaluated by using the location and attributes of building elements, such as the weight of elements or materials of elements. Therefore, the authors propose the 3-D graphical simulation system for crane planning, with an object-oriented building product model.

This paper presents the development, present status and future directions of the 3-D graphical simulation system for crane planning using the object-oriented building product model. The work described in this paper is still in progress. The paper will conclude with a layout of future plans for 3-D graphical simulation systems as the tool of virtual construction.

1. Introduction

A number of computer-based simulation systems have been developed for the A/E/C industry. However, most of these simulation systems only support the limited domains such as structural analysis or cost simulation. On the other hand, there are few simulation systems which can support the construction simulation. However, these current construction simulation systems do not have enough capability to

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support even the most basic construction site elements or do not have enough user-friendly interfaces which easily simulate various situations according to the construction site restrictions.

Therefore, any construction planner or construction manager has to spend considerable time to get the sufficient simulation results from these simulation systems. Most systems do not have the following functions:

Quick Modelling --- How to input the building elements easily and quickly in order to do a simulation.

Full 3-D Capability --- How to prepare the 3-D crane data with its functions as an attribute.

Parallel Simulation --- How to make a multiple plan and compare the cost, quality, safety or duration in order to select the best plan.

Documentation of Results --- How to get the simulation results in the form of a drawing document, animation, estimation sheet, and so on.

Therefore, the authors have been proposing the 3-D graphical simulation system for crane planning, with an object-oriented building product model. The main functions of this simulation system are:

To propose the easy and quick modeling functions to define the building elements, which is independent on any CAD systems.

To propose the list of appropriate cranes by evaluating the building elements location, elements weight, element shape and crane position.

To propose the schedule and cost of the crane by evaluating the number of elements and the crane’s loading ability.

To simulate the steel construction work graphically by using the definition of construction zone and construction schedule.

To provide several kinds of documents such as 2-D drawings, specifications, estimation sheets and bar chart diagrams which will be created from the simulation results.

2. Crane Planning

There are several kinds of restrictions for construction operation, such as the site area, site condition, regulations, human resource restriction, equipment restriction, construction duration, construction cost and so on. Therefore, the following works are very important to proceed with a well-managed construction operation:

How to evaluate the several kinds of restrictions before or during construction as quickly as possible.

How to make the reasonable construction plan while considering the quality of the facility, construction cost, construction duration and labor safety.

How to prepare computer-based systems which support the construction management during the construction operation which takes in effect unexpected site situations, such as delay of schedule, lack of human resources, construction accident and so on.

Planning for crane is an especially important and difficult task at the construction planning or construction stage, because this planning is strongly related to the construction method selection and influences the overall construction operation. Therefore, the computer-based simulation system for crane planning should have following functions:

Recognition of the shape and area of the construction site and structure or height of neighborhood units around the site.

Definition and recognition of the building elements with attributes which are evaluated by the crane simulation.

Providing the graphical user interfaces which establish the ease of simulation such as to input, to move, to delete the crane and to store it into the file in order to re-evaluate it later.

Providing safety information according to the crane plan during the simulation.[Ito 95b],[Ito 95C]

Providing useful output of simulation results such as drawing documents, specifications, construction schedule and so on.

As the first step in developing the well-designed crane simulation systems, the authors have been capturing the behavior of the human experts at the crane planning, because the crane is the most expensive resource and most construction planner or manager carefully selects the crane with the combination of construction methods in order to keep the constructability and productivity of construction.

The construction planner should consider the following subjects at the crane planning stage:

The selection of the crane according to the site restrictions, such as number of structural pieces, maximum weight of building elements, site area and so on.

The positioning of the crane according to the site restrictions, such as weight of each building elements, position of highest building element, distance of nearest and farthest building elements and loading ability of crane.

Interference between the built elements and boom of the crane considering zoning and sequence of construction. (Figure-1 and Figure-2)

Total construction period and cost by using the selected crane.

This system provides the various simulation functions such as changing of crane position, changing of the type or ability of crane, changing the sequence of erection, according to the interference evaluation.

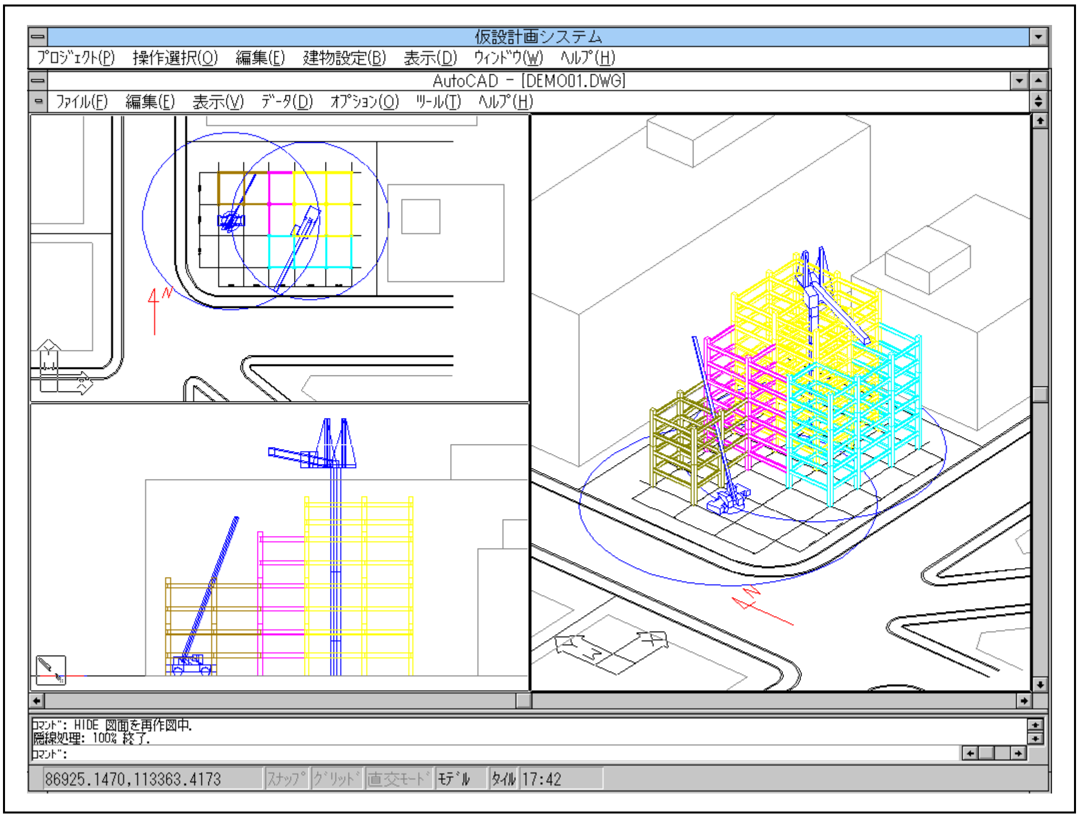
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Figure - 1: Interference Evaluation between Cranes

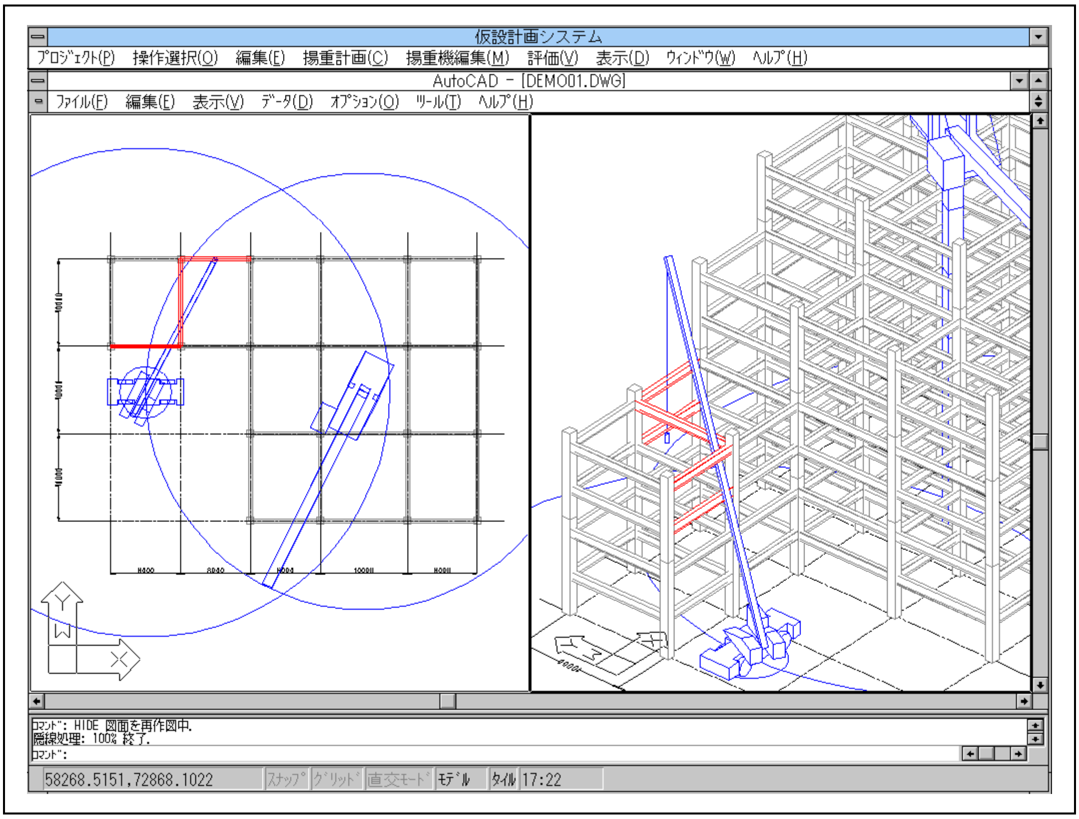
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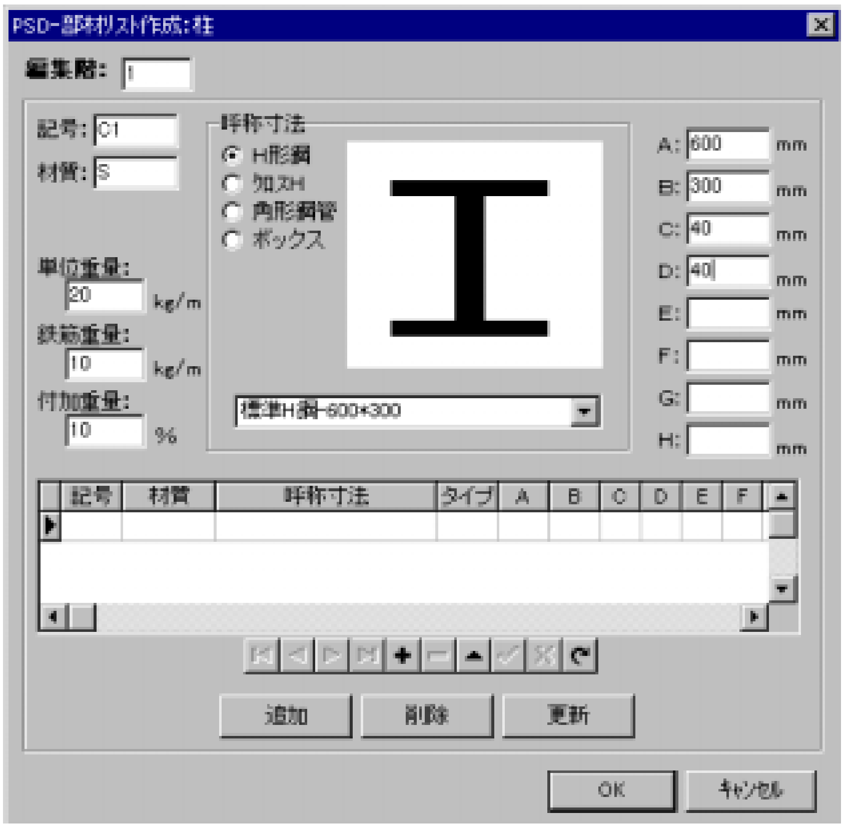
Figure - 2: Interference Evaluation between Crane and Elements



PSD-部材リスト作成:柱

編集階: 1

記号: C1

材質: S

単位重量: 20 kg/m

鉄筋重量: 10 kg/m

付加重量: 10 %

呼称寸法: ● H形鋼 ○ 加工H ○ 角形鋼管 ○ ボックス

標準H鋼-600*300

A: 600 mm

B: 300 mm

C: 40 mm

D: 40 mm

E: mm

F: mm

G: mm

H: mm

Figure - 3: Screen Image of Element Definition

3. Object-Oriented Product Model

For the crane planning, building elements should have the following information in order to establish the several kinds of simulation:

3-D topological information.

Type, shape and material of elements.

Relationship between other elements.

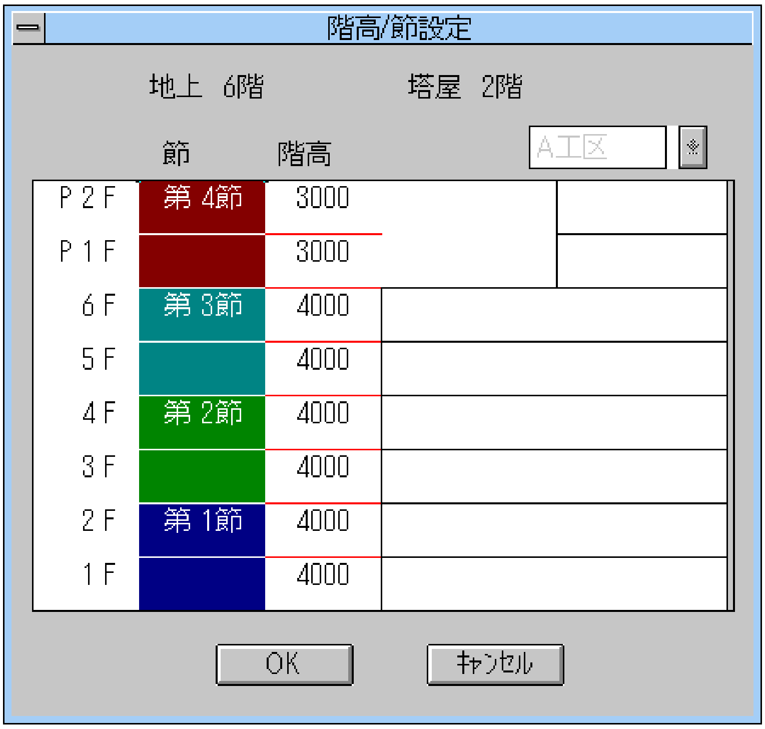
Floor and zone information.

Figure-3 shows the example of the user interface of building element definition. In terms of the crane simulation, defining of the detail section information of building element with material information as an object is needed to evaluate the loading ability of crane and positioning of crane. On the other hand, defining the relationship between elements as an attribute of an object is very useful to evaluate the sequence of erection and interference between built elements and boom of the crane.

In this system, the following physical and non-physical elements are defined as an object using the previous user interface:

Construction Site, Adjacent Properties, Column Line, Floor, Erection Stage, Zone and Volume. (Figure-4)

Column, Beam, Wall, Slab and Free Element. (Figure-3)



地上　6階　　塔屋　2階

	節	階高
P 2 F	第 4節	3000
P 1 F		3000
6 F	第 3節	4000
5 F		4000
4 F	第 2節	4000
3 F		4000
2 F	第 1節	4000
1 F		4000

Figure - 4: Definition of Floor and Erection Stage

At the beginning of this project, this modelling function was consisted in the user interface for the section definition by Microsoft Visual Basic, and for inserting element data or displaying inserted element by AutoLisp. And interface between the section definition and inserting project data is realized by the DDE linkage of Microsoft Windows. However, for the future extension and the system response, this modelling function is re-developing as a common modeller and the CAD independent system using Boland Delphi, and the result of this re-development, new modelling function can provide the product model to the couple of systems, such as 3-D graphical simulation system and Walkthrough system. Moreover, this system provides the interface functions in order to import the 3-D structural data from structural design CAD system and to export the 3-D building data to the 3-D shop drawing CAD or the displaying image to the 2-D shop drawing CAD systems. Figure-5 shows the class hierarchy of this system. This class structure is realized by using the ***blocks*** of AutoCAD in this simulation systems. Similar approach to describe the product data using the ***blocks*** was proposed and proved by author.[Ito 90]

4. Visualization and Documentation

During the crane simulation, several kinds of conditions will be defined, changed and fixed according to the selection of the crane, position of the crane, zoning plan, cost estimation and period evaluation. Through this process, the user would like to print out or save the simulated results as a 2-D drawing document, estimation sheet, bar chart diagram and so on in order to find the best plan from their simulation.

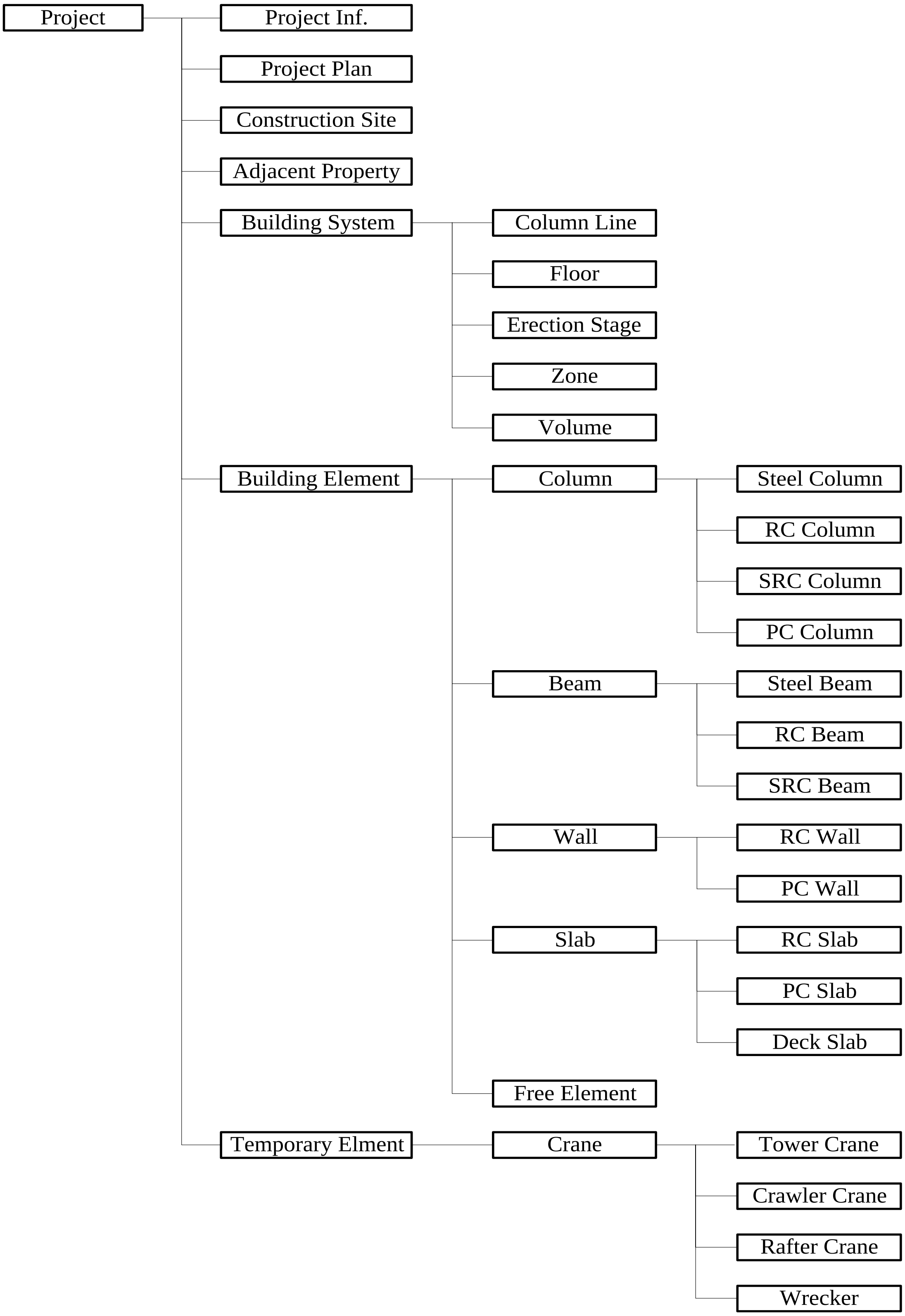

Project
Project Inf.
Project Plan
Construction Site
Adjacent Property
Building System
Column Line
Floor
Erection Stage
Zone
Volume
Building Element
Column
Steel Column
RC Column
SRC Column
PC Column
Beam
Steel Beam
RC Beam
SRC Beam
Wall
RC Wall
PC Wall
Slab
RC Slab
PC Slab
Deck Slab
Free Element
Temporary Elment
Crane
Tower Crane
Crawler Crane
Rafter Crane
Wrecker

Figure - 5: Hierarchy of Object Class

Therefore, this simulation system provides the following documents:

- 2-D drawing documents which captures the screen image to the DXF format and output to the printer/plotter or any other 2-D CAD systems.

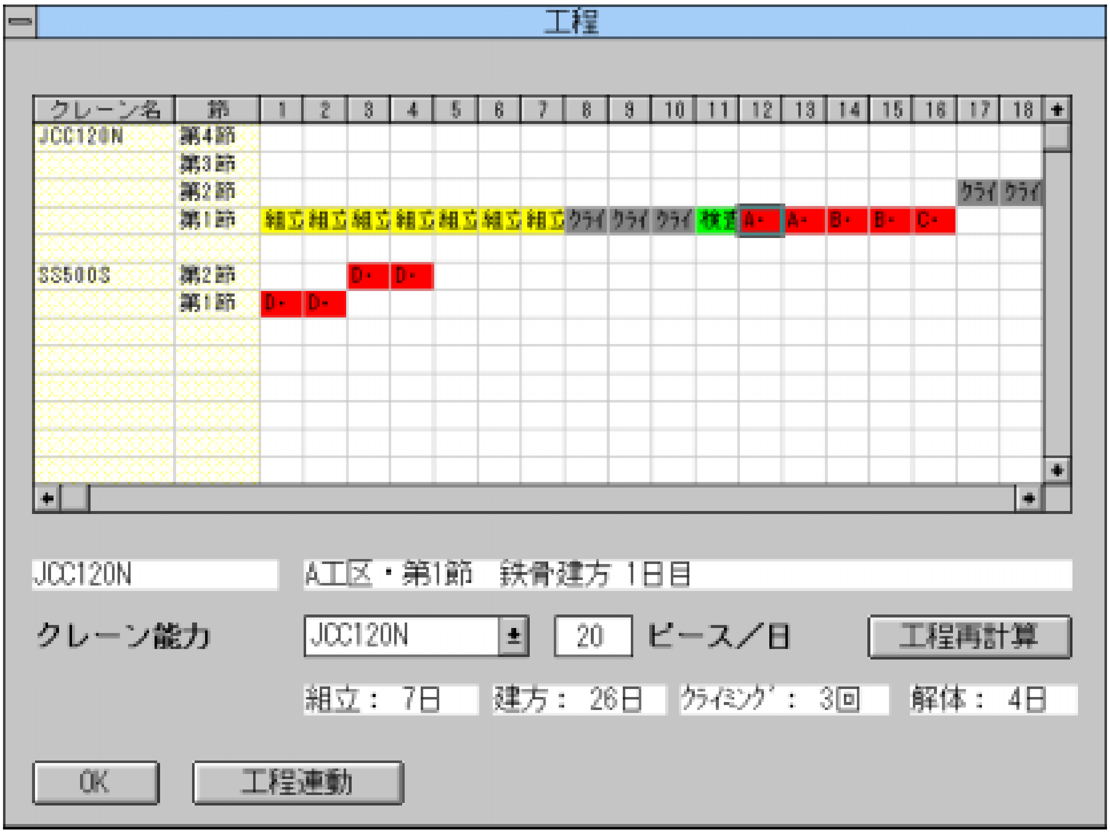


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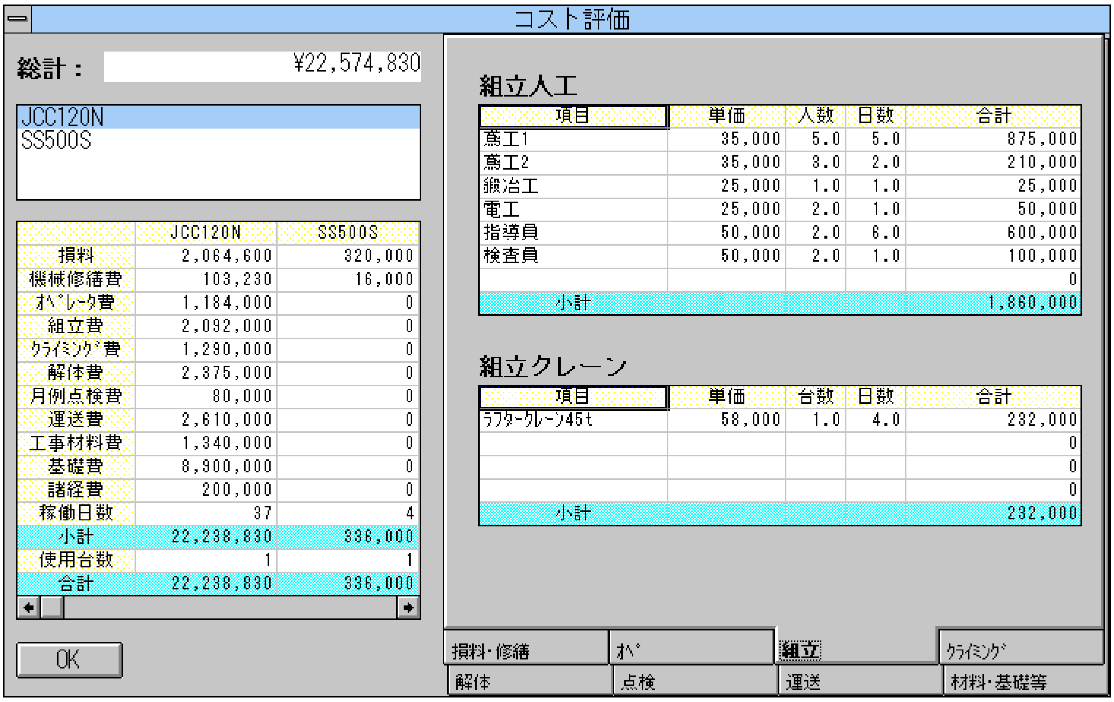
Figure - 6: Lifting and Climbing Schedule Evaluation

- Bar chart diagram which evaluates the number of structural steel pieces from the crane ability which stored into the crane database. (Figure-6).This schedule data can export to the in-house construction management system.[Ito 95a]
- Crane cost estimation which evaluates the duration of erection work and rental cost of the selected crane from the above crane operation schedule. (Figure-7) After the crane cost estimation, cost information is transferred to the in-house pricing system and the user can get the formal pricing sheet.
- Formal documents which should be submitted to the government office or branch office are created automatically from this system as a result of simulation.
- Past construction accident data which related to the temporary facility work, can refer from this system in order to forecast or prevent to the future accident.
- Erection sequences will be displayed on the screen which is according to the designated zone and erection stage by user.

These additional functions of a simulation system provide the integrated environment to the construction planner and construction manager before and during construction operation.



総計：¥22,574,830

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損料	2,064,600	320,000
機械修繕費	103,230	16,000
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工事材料費	1,340,000	0
基礎費	8,900,000	0
諸経費	200,000	0
稼働日数	37	4
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使用台数	1	1
合計	22,238,830	336,000

組立人工

項目	単価	人数	日数	合計
鳶工1	35,000	5.0	5.0	875,000
鳶工2	35,000	3.0	2.0	210,000
鍛冶工	25,000	1.0	1.0	25,000
電工	25,000	2.0	1.0	50,000
指導員	50,000	2.0	6.0	600,000
検査員	50,000	2.0	1.0	100,000
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Figure - 7: Crane Cost Estimation

5. Conclusion and Discussion

This paper described a 3-D graphical simulation system for crane planning with an object-oriented building product model that supports simulation, visualization and documentation of crane planning with user-friendly interfaces. Currently, this simulation system has been developing and will apply to actual construction planning from this October. The most important point of developing this system is proved the concept of the new type of 3-D graphical simulation with the evaluation of cost, schedule and other planning factors.

During the course of developing this simulation system, the advantage of object-oriented building product model and integrated system environment for construction planning and management in the A/E/C industry has been found and discussed. The new modeller, which is using this simulation system, is independent on any CAD systems. Currently, this modeller has own data format and can provide the several kinds of file format such as 3-D DXF and so on. Then this modeller will be used by not only this simulation system or Walkthrough but also structure design system or production planning system. Moreover, in future, when the ISO/STEP or IAI/IFC will be established, by changing the data format of this common modeller to use these standard, the integrated system environment will be realized by this modeller.

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