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4D CAD-based evaluation system for crane deployment plans in construction of nuclear power plants

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ABSTRACT

To optimize a crane deployment plan is an important problem to reduce construction cost. Previous researches focused on developing methods to find an optimal crane deployment plan automatically, which minimizes total operating time under physical constraints such as load capacity. These researches did not focus on evaluating transitions of crane utilization rates during construction period. Unlike a general tall building, construction schedules of a nuclear power plant (NPP) tend not to take the form of a series of construction cycles in a typical floor. Therefore, transitions of crane utilization rates need to be evaluated in construction of a NPP.

The purpose of this paper is to develop a 4D CAD-based evaluation system, which calculates transitions of utilization rates automatically, for planning of crane-deployment in construction of a NPP. To calculate utilization rates automatically and accurately, two functions were developed. The first function maps data between 3D objects and carry-in tasks by using a fast geometric interference checking method based on "Axis Aligned Bounding Box." The second one estimates installation material quantities in early construction-planning phases by using a data mining technique called "random forests." The result of verification tests based on previous construction data indicates that the proposed system will significantly reduce the time required to create crane-deployment plans and improve their accuracies.

1. Introduction

A nuclear power plant (NPP) is composed of a lot of facilities classified into categories such as mechanical, electrical, and HVAC (heating, ventilating, and air conditioning). For example, the number of pieces of equipment reaches several thousand, and the total length of piping components reaches 100,000 km. These facilities are complicatedly arranged in several hundred areas surrounded by thick concrete walls. Unlike a general tall building, floor plans of a NPP differ widely according to floor so that construction schedules of a NPP tend not to take the form of a series of construction cycles in a typical floor. Therefore, as a project, constructing an NPP is so large and complex that it needs several years and billions of dollars to complete, and any delay to the project causes a huge loss.

The "open-top construction method" is adopted for a NPP [1,2]. As for this method, activities involved in constructing buildings and installing facilities are carried out concurrently at the construction site of an NPP. Although this method can reduce the construction period, it requires cranes to be shared between companies in charge of the two types of activities, namely, building frame work and equipment work. Therefore, properly drawing up plans for deployment of cranes, which contain the number of cranes, their locations, and a schedule to use them, is vital in regard to preventing delays of construction projects.

In terms of efficiency, the quality of plans for deploying cranes depends on a planner's know-how based on their experience. If the demands for cranes exceed the cranes' capacities, and delays are forecast, additional cranes must be deployed and overtime work must be scheduled. These measures naturally increase costs. To solve this problem, it is necessary to develop a system that can create robust plans without the need for skillful planners on the basis of rules extracted from previous statistics concerning construction data.

One of the ways to evaluate crane-deployment plans quantitatively is to estimate the utilization rates of cranes. It requires determining which cranes are assigned to each material. However, it is a problem that the number of materials used in constructing a NPP is too large to determine the assignments of cranes manually. Additionally, it is also a problem that the quantities of materials required and the number of facilities to be built is uncertain in early planning phase of crane-deployment. This is because engineering of a NPP is not complete at that time owing to the concurrency between engineering and construction planning.

Researching methods for creating accurate crane-deployment plans effectively, Huang et al. have developed a planning method (which applies a mixed-integer linear-programming technique) for automatically creating deployment plans for tower cranes [3]; Lien et al. have

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developed a method that applies the "particle bee algorithm" [4]. These methods calculate crane deployment plan automatically; however, these researches mainly target general tall building so that they do not refer to transitions of crane utilization rates. This is because construction schedules of general tall building tend to take the form of a series of construction cycles in a typical floor. On the other hand, floor plans of a NPP differ widely according to floor so that crane utilization rates are possible to differ widely by floor. Therefore, evaluating transitions of crane utilization rates is important in NPP construction to reduce deviations and improve productivity.

In addition, these researches do not refer to how to prepare the input data such as material quantities carried by each crane. To reduce manpower to prepare the input data, Wang et al. have developed "Firefly Algorithm" combined with building information modeling (BIM) [5]. In this research, material quantities carried by each crane is automatically calculated based on Construction BIM(C-BIM), which includes construction support models such as scaffold and formwork. However, in construction of NPPs, C-BIM is not completely created. For example, it is often the case that support models are created not as 3D model, but as 2D model. Also, in early planning phase, quantities of some kinds of materials such as piping components are not fixed. Therefore, material quantity take-off is a critical problem for optimal crane deployment plan.

To evaluate transitions of crane utilization rates based on crane deployment plans and construction schedules, we have focused on 4D CAD, which integrates 3D models and a time dimension. 4D CAD was used to visualize construction schedule as intuitive animation for validating construction plans [6–9]. As a result of these researches, 4D CAD has become so prevalent that commercial 3D CAD software includes a function for it. Recently, Kang L. S. et al. developed a 4D CAD-based simulation system for evaluating and visualizing risks involved in a construction project [10].

In this study, a simulation system for evaluating and visualizing the validity of crane-deployment plan was developed. 4D CAD was used to calculate transitions of utilization rates of cranes, and a data mining technique called "Random Forests"(RF) [11] was used to calculate material quantities from incomplete C-BIM in early planning phase.

2. Planning of crane deployment

2.1. Crane deployment

For constructing facilities in buildings in a NPP efficiently, it is important to deploy cranes properly. Two types of cranes are deployed during construction of a NPP a tower type (which moves up and down while fixed in a stationary position) and a crawler type (which moves up and down and can move along the ground by caterpillars). As shown in Fig. 1, the area in which a crane can operate ("operating area" hereafter) is modeled as a cylinder with radius equal to the operating radius of the crane. As shown in Fig. 2, all materials and facilities must be covered by the operating areas of cranes. The number of cranes is also a key consideration. If it is too low, the utilization rates of the cranes will exceed their capacities. On the other hand, an excessive number of cranes incurs large costs and may cause physical interference between operating cranes. Additionally, the load limits of cranes must also be considered.

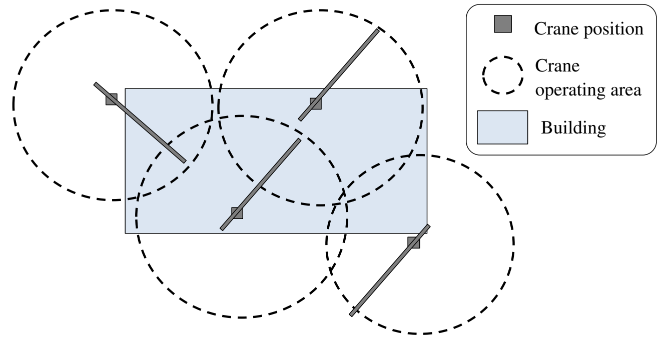

Fig. 2. Image of a deployment of cranes.

2.2. Carry-in schedule

A sequence of building frame work and equipment work, especially for carrying equipment and piping components in buildings, is shown in Fig. 3. In steps 1 and 2, floors and walls of areas are constructed. In step 3, facilities such as equipment and piping components are carried into those areas from above by cranes. In step 4, the ceilings are constructed. After step 4, the facilities are installed in those areas. The main reason for this sequence is that large facilities cannot be carried into areas through delivery entrances of the building after the ceilings of the areas are added. Although this sequence of building works and mechanical and electrical works in an area are conducted in series, such works in several areas are conducted concurrently.

Materials and facilities carried into areas in buildings are categorized in two types: (a) building frame works such as structures, rebar, molds, and scaffolding, and (b) mechanical and electrical works such as equipment, piping components, operating platforms, metal components, and scaffolding.

Each activity in work schedules has attributes such as building name, floor name, names of NPP systems, and drawing number. These attributes make it possible to automatically link activities to 3D objects, which is called mapping hereafter. An example of mapping is shown in Fig. 4. It is supposed that activities have the area names where they

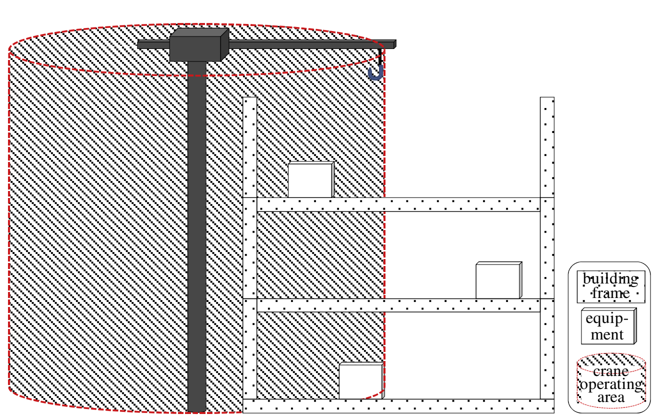

Fig. 1. Image of an area in which a crane operates.

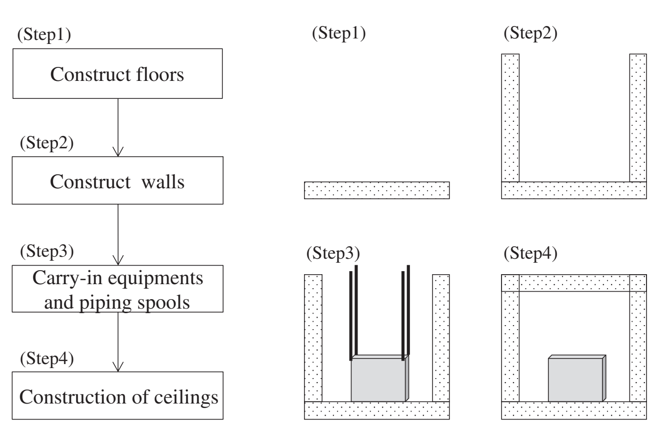

Fig. 3. Construction steps performed in an area(left), and image of construction sequences performed in an area(right).

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