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Development of a schedule-workspace interference management system simultaneously considering the overlap level of parallel schedules and workspaces

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ABSTRACT

Schedule-workspace interference is generated when workspaces that share parallel schedules and are physically adjacent to one another exist simultaneously. When workspace interference is generated, securing work performance safety is difficult and constructability can deteriorate due to increased collision risk between resources. The objective of this study is to realize an active simulation system based on building information modeling (BIM) after constructing a genetic algorithm (GA) process for an alternative schedule that minimizes the simultaneous interference level of the schedule-workspace. To accomplish this task, the impact factor of workspace interference, which simultaneously considers schedule overlap and adjacency, was analyzed. From the impact factor, an optimized algorithm based on a location-constraint GA that can minimize workspace interference is suggested. The GA visually simulates the optimization level of the execution schedule compared to the initial plan through interlock with four-dimensional (4D) computer-aided design (CAD). A 4D CAD system that can analyze workspace interference by a GA was developed, and for the developed algorithm and system, a case verification was attempted for a railroad construction project. The results show how a simple visualization-oriented BIM system can be extended to an active schedule management system equipped with decision-making functions of workspace analysis.

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1. Introduction

When parallel activities located in adjacent spaces progress simultaneously, workspace interference is frequently generated, deteriorating the safety and constructability of work. Typically, when workspace interference is generated at the job site, resource input is controlled by the situation of the job site only, or schedule of activity is forcibly adjusted with empirical methods. These methods might not be reasonable because the level of interference elimination cannot be foreseen. If a workspace analysis method is interlocked with four-dimensional (4D) computer-aided design (CAD), its effectiveness can be improved because the level of space interference in accordance with the schedule is visually expressed. Most existing workspace control research or systems consist mainly of a simple situation expression of workspace interference in accordance with changes in schedule information. Therefore, it is difficult to analyze the change in space interference and the optimum state in connection with the level of elimination of the activities in which overlap has been generated. Given these limitations, providing the decision-making function for establishing alternative schedule and workspace interference optimization is insufficient. Therefore, an additional decision-making process based on specialized knowledge on the schedule control of the corresponding staff in charge is needed. If workspace interference can be solved through schedule adjustment by a 4D CAD system, this function can be utilized as the decision-making function, which can simultaneously minimize schedule overlap and the physical interference level of adjacent workspaces.

In this study, to improve situation expression-oriented interference control systems of workspace collision, a method of performing connected analysis of schedule and workspace within the 4D CAD environment is suggested in an analyzed algorithm and system. This study develops an algorithm for establishing a schedule plan with which schedule and workspace interference become simultaneously minimized, and it develops an active workspace interference optimization system based on this method. For these purposes, first, an estimation method for a schedule-workspace interference impact factor based on schedule overlap and adjacency information of the workspace in a project is established. Second, a schedule-workspace interference optimization algorithm based on a location-constraint genetic algorithm (GA) is analyzed. Based on this analysis, the simultaneous overlapping state of the schedule-workspace can be visually confirmed, and with optimized

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workspace interference information, an active 4D simulation system that can mutually be compared with the planned schedule is developed. Finally, the proposed methods and practical utilization of the developed system are verified through a case study of a railroad construction project.

This study also presents an alternative schedule in accordance with the interference elimination level through simulation by optimizing selectively or in combination with the schedule and workspace overlap. Therefore, it is expected that simple visualized function-oriented building information modeling (BIM) system can be extended to an active system.

2. Current research and improvements of this study

2.1. Current research

Numerous studies related to work schedule, workspace interference, and BIM, including 4D CAD, have been performed. Bansal [2] studied manual adjustment of total float (TF), space location change in accordance with positional relationships of GIS, and other factors to solve workspace interference problems. Akinci et al. [1] asserted that schedules could be utilized for automated revision [27,28] to minimize space collision of a space-loaded production model. Zouein and Tommelein [33] proposed an improved space scheduling method considering resources and schedules to optimize the arrangement of restricted site space. Related to this topic, studies on the optimum arrangement of a temporary facility and construction site that considered safety by utilizing a GA technique for the arrangement of the work area [8,25], optimum arrangement of a construction site by GA [20,32], site arrangement optimization by utilizing particle swarm [31], and a CAD-based site arrangement plan [24] have been performed. Easa and Hossain [7] presented a new mathematical model for optimum arrangement of a temporary facility considering adjacency constraints between areas of a corresponding facility. Hagazy and Elbeltagi [12] developed an evolutionary computation-based site arrangement plan model (EvoSite) in which the system was integrated with a built-in GA method to optimize the arrangement of facilities at a construction site. Cheung et al. [5] applied a GA to solve pre-fabrication shop arrangement problems of a site.

Recently, particularly in the area of schedule optimization, studies on the optimum distribution of corresponding information through independent optimization of schedule information, as well as through mutual exchange of resources [26], cost [9], and equipment [14] managed in connection with the former, have been reported. Hagazy et al. [13] constructed a GA-based distributed scheduling model (DSM) that optimized schedule, resources, and cost to determine routing sequences and optimum construction methods between dispersed construction sites. To minimize project time, Zhang [30] applied an ant colony-based optimization method to solve multiple resource-constrained project scheduling problems. Jun and El-Rayes [15] applied a multi-purpose GA method that minimized construction time and resource changes so that the efficiency of resource utilization could be maximized by considering the preceding and subsequent relationships and resource availability constraints.

To achieve dynamic control of schedule information through interlock with 3D information, several studies have developed 4D CAD systems [10,17,19,21,29]. Russell et al. [23] developed a 4D CAD system that could efficiently perform safety and construction management work in the planning, design, and construction stages by considering linear scheduling as the schedule information. Kang et al. [16,17] presented a 4D CAD system that utilized work breakdown structure (WBS) code so that schedule and progress control work could efficiently be performed from construction work, and they also presented an example of developing a 4D CAD system for utilization of simulation information during a road construction. In addition, 4D objects have been applied to safety management [3] and workspace visualization analysis [1,4,6,22].

2.2. Improvements compared with current research

In general, existing schedule-workspace interference control has been performed through manual adjustment of TF and adjustment of positional arrangement relationships of spaces. Optimization studies have been performed by considering the load with resources. Because numerous studies simply place the focus on realizing mathematical models, additional, specialized knowledge is required to apply the schedule-workspace interference results to the job site. In addition, many studies on optimization of work zone arrangements, such as arrangement of temporary facilities, work areas, and so forth, have been performed. These studies establish arrangement plans through the interrelation of adjacency, safety, and cost between outside work areas without considering connectivity with schedules. In addition, studies on schedule optimization have focused on the optimization of schedules only, schedule combinations that consider cost and construction methods together with GA application, and schedule plans for resource equalization.

In this type of study, the workspace is not simultaneously considered the optimization subject of the schedule plan; therefore, establishing the optimum schedule plan in which schedule overlap and space interference are simultaneously considered is not easy. Current 4D CAD systems have mainly been used to analyze application examples of practical projects, constructability by visualized models, examination of construction error, and progress monitoring using commercialized systems.

Compared with these previous studies, items that this study attempts to improve upon are as follows.

1) Suggestion of the schedule-workspace interference impact factor: This study presents the impact factor of schedule-workspace interference, which simultaneously considers the overlap ratio of the schedule and the adjacency of the workspace. This impact factor can be utilized as the standard of evaluating the constructability to perform the work without interference from other workspaces for activities whose workspaces are adjacent and which progress simultaneously and in parallel. In addition, the impact factor is utilized as the standard of the objective and fitness function during the performance of schedule optimization, and it can be utilized as the standard of comparing and evaluating the elimination level of workspace interference by optimized schedules compared to planned schedules.
2) Location constraint-based GA application for the simultaneous optimization of schedule-workspace: To minimize schedule and workspace interference simultaneously, a revised GA is applied in the study. To this end, genetic operation was performed for the remaining activity except the critical path (CP) from the generation of the solution to the stage of evaluating fitness for each generation of the solution population. This operation reduces the complexity of the calculation for maintaining multiple preceding and subsequent relationships through the application of the GA to the CP, and it allows for the creation of an optimum schedule combination in the shortest time through rapid search.
3) Development of a BIM-based simulation system for schedule-workspace interference optimization: This study suggests a BIM-based simulation system that allows for the presentation of optimum alternative schedule plans that consider the actual work circumstances of the construction site. When considering that existing 4D CAD systems have focused on the simple visualization-oriented passive simulation environment compared to the construction schedule, the system developed in the study presents improved functions as a system of the active BIM environment, providing visual expression by establishing an optimum schedule plan in which schedule and workspace interference are minimized.

In this manner, a schedule-workspace optimization process by an improved GA technique is integrated into a 4D CAD system. Therefore, this operation system can be utilized as a separate decision-making process

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