Automation in Construction 16 (2007) 262–276

AUTOMATION IN CONSTRUCTION

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# Automated generation of workspace requirements of mobile crane operations to support conflict detection

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Accepted 30 May 2006

**Abstract**

Modeling workspace requirements related to mobile crane operations could minimize delays associated with spatial conflicts and hazards on construction sites. To identify spatial conflicts related to crane operations, project engineers need to model and reason about spatio-temporal behaviors of cranes and coordinate them within a dynamic construction environment across time. Current approaches for identifying equipment-related spatial conflicts are based on discrete-event simulation of dynamic equipment motion. The accuracy of spatial conflicts detected using such approaches can be error-prone since it depends on a rate of time increment for the simulation to be set by the user. This paper presents an approach for generating workspaces that encapsulate spaces occupied by mobile cranes moving during an operation. It also discusses an assessment of the effectiveness of the approach in identifying spatial conflicts between mobile cranes and building components.


*Keywords:* 4D CAD; Equipment; Crane; Workspace; Spatial conflict; Conflict detection

## 1. Introduction

Mobile cranes are widely used on construction sites for lifting materials. Compared to other types of construction equipment, mobile cranes typically occupy relatively large workspaces in three dimensions (3D) during an operation. When the workspace of a crane is not taken into account prior to its operation, the potential for spatial conflicts between the crane and other components (e.g., existing building facilities, temporary structures, and other construction equipment) located within the proximity of the crane increases [1–3]. Existences of such spatial conflicts can potentially result in work interruptions, productivity reductions, hazardous work conditions, and damages to existing structures [1,2,4,5]. As reported by Occupational Safety and Health Administration (OSHA), 40% of the deaths involving cranes on construction sites from 1984 to 1994 were related to spatial conflicts [6]. These all suggest the need for modeling the workspace requirements of cranes so that project engineers and operators can be aware of possible spatial conflicts ahead of time and can accordingly take necessary preventive actions.

Space available for crane operations on construction sites is typically limited by facilities under construction and activities being executed concurrently and in close proximity [1]. Existing structures, such as electric lines and building structures, can have spatial conflicts with crane operations [2,7]. To assess the availability of space on construction sites and to identify spatial conflicts, one needs to represent and reason about not only crane workspaces but also components that are expected to be in place at a given time of operation in three dimensions.

A major challenge in modeling workspace requirements of cranes stems from the fact that crane operation is dynamic. Although cranes are typically located at fixed places, some of their parts, such as their booms and hooks, move during an operation. These movements result in changes in the workspace requirements of cranes over time during a given operation. Hence, to identify crane-related spatial conflicts, one needs to account for the dynamic behavior of cranes and their parts and the corresponding changes in the workspace requirements over time.

Currently, commercially available visualization tools based on discrete-event simulation, such as Bentley Dynamic Animator [8], allow project engineers to model and visualize dynamic motion of

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doi:10.1016/j.autcon.2006.05.007

equipment in conjunction with the evolution of constructions in three dimensions and over time. Within such systems, spatial configurations of pieces of equipment are modeled and visualized in four dimensions based on a set of user-defined information characterizing the motion of each part of equipment at discrete points in time. During simulation and visualization, such systems perform collision detection tests to identify possible spatial conflicts between pieces of equipment and building components at each incremental time step selected by a user.

Spatial conflicts detected using such simulation and visualization tools can be error-prone as the increment in discrete time steps of the visualization needs to be set properly by a user. If users select a very fine time increment, it will be possible to accurately identify possible spatial conflicts. However, a fine time increment could result in a large amount of time dedicated to visualization of construction operations. For example, in our experiment, we identified that when we selected a time increment as small as 1 s, we could identify all possible spatial conflicts that occur while a crane is lifting and placing a single component [2]. Visualizing this crane operation took approximately 1 min on an Intel Pentium 4 2.2 GHz computer, while the actual operation on the job site took 10 min. Since construction projects typically involve large quantities of building components and corresponding crane operations, visualization of operations and detection of related spatial conflicts throughout the entire construction period with fine time increments can become prohibitively time-consuming.

Instead of a fine time increment, a user may opt to use a coarse time increment for visualization of operations throughout the entire period of construction. For example, if the user selects a time increment as large as 1 day, visualizing construction operations of a project with a total duration of 5 months can take approximately 1 min on the same computer. However, with such a coarse time increment, it is likely that some potential spatial conflicts can be missed since a crane can perform multiple operations on a given day.

These all suggest that the accuracy of detected spatial conflicts be not rely mainly on a user-selected time increment of discrete-event simulation. This paper focuses on this need to model and identify possible spatial conflicts during an equipment operation without the reliance on a user-selected time increment. It presents an automated approach for generating workspace requirements of mobile cranes to enable automatic identification of spatial conflicts related to crane operations. It also describes the validation performed to assess the effectiveness of such an approach in detecting spatial conflicts related to mobile crane operations.

## 2. Previous research

The research described in this paper is related to and builds on previous research studies within areas of visualization of construction activities and operations, planning for material-lifting operations, and collision detection.

### 2.1. Visualization of construction activities and operations

Construction visualization tools provide a visual environment for analyzing a plan based on discrete-event simulation of construction processes and for identifying potential spatial conflicts in three dimensions and across time. Kamat [9] identified two levels of detail at which construction processes are visualized and modeled: *project*-level and *operation*-level of detail.

At the *project*-level, a construction activity relates to building components, and the progress of construction is visualized as a set of building components being constructed over time. An example of project-level visualization is 4D CAD simulation, which centers around integration of product (3D) and process (1D) information models [10–12]. While 4D CAD simulation is performed, one can check for possible spatial interferences between building components during construction.

The *operation*-level visualization provides information related to dynamic motion of resources (e.g., crews, pieces of equipment, and materials) used during operations, which describe technological methods used on a site to achieve a specific end product. To visualize dynamic motions of the resources, information related to geometric transformations (e.g., type of motion, duration of motion, etc.) of those resources also needs to be modeled [9]. Bentley Dynamic Animator allows users to model dynamic motions of objects in a scene and integrate them with process information [2,8]. With this feature, users can visualize not only project-level activities, but also motion of resources used by construction activities. Kamat [9] developed an approach (VITASCOPE) for generating a 3D animation of equipment operations based on a sequence of geometric transformations of pieces of equipment generated by discrete-event simulation.

Both Bentley and VITASCOPE have spatial conflict detection mechanisms implemented. In VITASCOPE, the spatial conflict detection mechanism is more efficient as VITASCOPE attempts to maintain an elapsed visualization time of an animation to be in proportion of an actual operation time while Bentley does not [13]. However, those two mechanisms check spatial conflicts at each frame update (or each incremental time step). Therefore, the accuracy of spatial conflicts detected depends on a time increment of the visualization. In certain cases, this approach can be error prone since the time steps, at which spatial conflicts are checked, need to be finer than the duration of motion of pieces of equipment. However, using finer time increments can lead to a visualization that takes long time.

### 2.2. Planning for material-lifting operations

In addition to general-purpose construction visualization tools, several research studies specifically address problems encountered in material-lifting operations and focus on operations of specific types of material-lifting equipment. They account for spatial conflict problems that can potentially occur during material-lifting operations. The research studies that are most relevant to the research described in this paper include determining crane locations [1,14] and planning crane motions [4,15].

Lin [1] developed approaches for determining the type and locations of mobile cranes by considering a reachable area of a crane, safety, and costs associated with crane operations. Zhang