

Identification and Resolution of Work Space Conflicts in Building Construction

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Abstract: Numerous workers, equipment, material, temporary facilities, as well as permanent structures share the limited space during construction. Since space constraints may affect productivity and the critical path, it is essential to organize the available space efficiently and minimize space conflicts. This study considers space availability due to time and scheduling, productivity loss due to space constraints and path interference, as well as the possibility of alternative space to resolve these conflicts and optimize space usage. Herein, computer-aided design is integrated with scheduling software for the dynamic identification of space conflicts on the jobsite. Follow-up supplemental decision criteria are then provided for conflict analysis and resolution. A prototype decision support system that combines the criteria was developed to solve this significant and complex problem more efficiently and precisely. A case study demonstrates the use and development of this system, which is very helpful to engineers and project managers.

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Introduction

Building construction involves various subcontractors working in a constrained area. Each subcontractor requires specific work space, equipment space, material storage, and travel paths as well as protected areas to complete his/her task. A crowded jobsite is a major cause of productivity decrease and schedule interference or delay. A detailed site layout plan with space allocation for subcontractors reveals the space conflicts in advance, and thus improves the overall work flow and efficiency. However, without a space management plan, the jobsite can become chaotic, filled with interfered workers, interrupted or inefficient work, schedule delays, and numerous complaints that can destroy morale.

Traditionally, a site engineer arranges the daily activities on the jobsite according to the planned schedule. However, this requires space allocation to various trades of workers during specific time frames. Space conflicts occur frequently on many jobsites, due to the lack of a formal procedure or methodology to identify all potential space conflicts. Even an experienced project manager may not be able to identify all of the conflicts; thus, traditionally, problems are dealt with as they arise. When serious space conflicts occur, the schedule is often delayed. Therefore, if a decision support system can be developed to help the manager identify space conflicts and suggest resolutions beforehand, then productivity will be essentially improved on the jobsite for all of the subcontractors.

Background

Space management involves three primary aspects of research—site layout planning, path planning, and space scheduling. First, site layout planning deals mainly with the layout of temporary facilities on the jobsite. Various approaches for locating the most appropriate layout of temporary facilities have been presented (Tommelein and Zouein 1993; Yeh 1995; Cheng and O'Connor 1996; Li and Love 1998; Hegazy and Elbeltagi 1999; Zouein and Tommelein 1999). Geographic information systems, artificial intelligence, and genetic algorithms have been used in previous studies to decide the best layout, according to the shortest travel distance or minimum travel cost between the temporary facilities. However, it is argued that a minimum traveling distance or cost applies only to a transportation optimization, and not directly to the optimization of the work itself, nor the shortest working period. Previous site layout studies did not pay enough attention to this argument. Furthermore, most of these studies did not consider the impact of time on space availability. For example, the jobsite office can be moved into the building itself when the structure is partially completed, thus releasing space for an alternative use. As well, time frame impact was neglected or oversimplified in most of these previous studies.

Second, path planning studies focus on the shortest route for construction equipment and operations. Based on work requirements and the starting and destination points, the shortest, collision-free path is identified by various algorithms (Varghese and O'Connor 1995; Lin and Haas 1996; Tserng et al. 1996). Typical applications include routing large vehicles or heavy-lift operations on the construction site as well as autonomous landfill using the global positioning system. However, since path planning studies are concerned mainly with equipment, generally workers and material storage are not included. Also, path planning researchers assume that space availability is fixed within a specific time period; that is, there is no consideration of the actual space variations during construction. These limitations constrain the significance of path planning studies on the improvement of construction productivity and space conflict resolutions.

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Table 1. Comparisons and Features of Space Scheduling Studies

Researcher	Time factor considered		Space user	Space overlap allowed	Space conflict analysis	Conflict resolution strategy
	Available Space	Working Space				
Tommelein	No	Yes	TF	No	No	No
Thabet	Yes	Yes	Worker, equipment, material	Yes	No	Schedule delay
Riley	Yes	Yes	Worker, equipment, material, TF	No	No	Yes
Akinci	Yes	Yes	Worker, equipment, material, TF	No	Yes	No
This study	Yes	Yes	Worker, equipment, material, TF	Yes	Yes	Yes

Finally, space scheduling combines all working elements (worker, equipment, material, path, temporary facilities, and physical layouts) subjected to the variations of time frames or schedules, and thus eliminates or minimizes space conflicts between these working elements. This complex problem involves space consideration as a resource, which varies with time. The space allocation procedure needs to be formally and accordingly executed based on a set of requirements or constraints of various working elements. Tommelein and Zouein (1993) developed MovePlan to determine temporary facilities according to the critical path method schedule. Thabet and Beliveau (1994) defined work space demand and availability for high-rise building construction. They also proposed the concept of the space capacity factor to describe productivity loss due to space constraints. Then, in 1997, a space-constrained resource-constrained scheduling system was developed. Riley and Sanvido (1995, 1997) defined construction-space use patterns in multistory buildings and presented a space planning method regarding various use patterns. Recently, 4D space planning specifications and construction work space development have been investigated (Riley 1998). Akinci et al. (1998) also executed similar research, which reduces non-value-adding activities due to time-space conflicts. Then, a time-space conflict analysis based on a 4D production model was proposed (Akinci and Fischer 1998).

Although many researchers have targeted this complex space-scheduling problem, few studies have used a formal procedure to analyze the patterns of space conflicts, and thus provide resolution strategies. Moreover, overlapping work space is not considered by most studies. Table 1 summarizes the major characteristics of previous studies, as well as the improvement through this study. This study has attempted to overcome those assumptions and derive a more thorough result than previous studies have achieved.

Research Structure

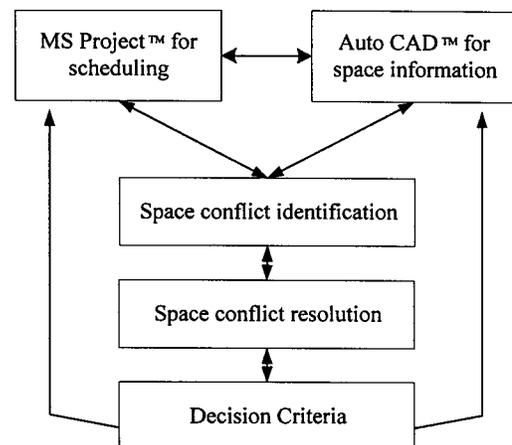
This study applied two typical tools, AutoCAD for space planning and Ms-Project for scheduling, to target the space conflict problem. Notably, both software packages are well known to most engineers. Once the space conflict is detected, the analytic flowchart provides an appropriate resolution strategy to eliminate or minimize the conflict based on the decision criteria developed herein. Fig. 1 shows the system structure. If the conflict is resolved by space reallocation, the resolution will be fed back to the computer-aided design (CAD) system. The CAD system will display the rearranged space planning result for various subcontractors. However, if the conflict cannot be eliminated, the system will then suggest a revised schedule, according to the minimized delay caused by space conflicts. Once the original schedule is adjusted to resolve the conflicts, the system will link to MS-Project to update the revised schedule for various subcontractors.

Fig. 2 illustrates the analysis flowchart. On completion of the project design, the associated construction method, original schedule/duration, required resources, as well as the CAD drawing are then determined. According to the above information, space availability and demand can be compiled based on various activities and time periods. Hence, a preliminary space plan can be derived for space conflicts analysis. Initially, this system will check if there is any space conflict between the subcontractors according to preliminary space planning. If any space conflict is identified, the system's decision criteria attempt to provide a resolution strategy to either resolve or minimize the conflict. When all of the conflicts are resolved, the system will execute the path demand analysis to verify if there is sufficient path space for worker/equipment traveling as well as material transportation. However, if the path demands cannot be satisfied, then the space conflict resolutions will be redone. Only when path demands are satisfied are the space conflicts really resolved and the final space planning complete.

Space Demand

The available space within building construction is divided into four categories—exterior of the jobsite, interior of the jobsite, inside the structure, and space provided by temporary structures such as platforms and scaffolds. The first two indicate only ground space. Available space inside the structure is then divided into various stories and zones. The total available space data are then compiled by the different codes of availability categories, which include the space size and time availability.

The space demand, which is derived from the original sched-

**Fig. 1.** System structure of space conflict resolution

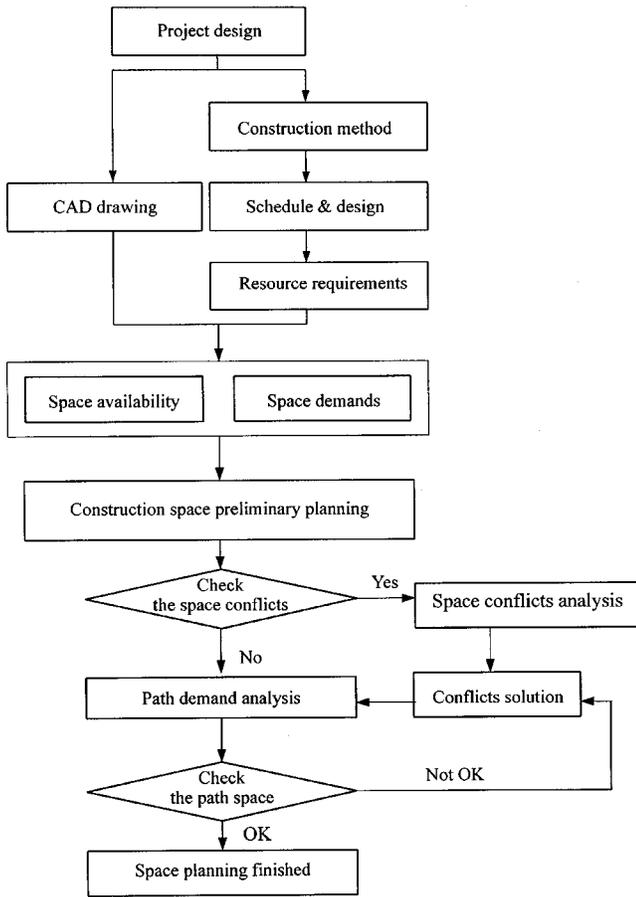


Fig. 2. Analysis flowchart of space planning and conflict resolution

ule and broken down as a hierarchical structure, is shown in Fig. 3. Notably, an activity may include several tasks and require various working and path spaces for laborers and equipment as well as associated material storage.

For various activities, different colors are applied for identification within CAD. Fig. 4 displays the different line patterns for the various spaces, such as working, storage, waste, or setup space. Notably, the crossed line represents working space, while

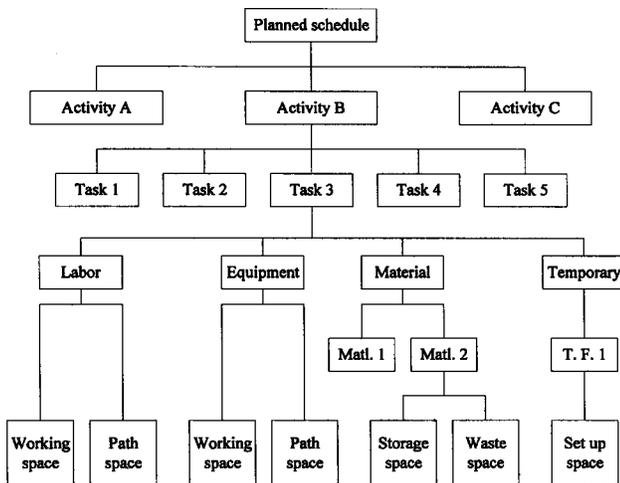


Fig. 3. Hierarchical structure of space demand

Space user	Labor	Equipment	Material	Temporary Facility
Type of space	Working space	Working space	Storage space	Set-up space
Identification				

Fig. 4. Identification of various space demands

the equipment working space uses a darker line than the labor working space does. Furthermore, a double crossed line designates material storage space, and a straight line identifies the setup space of temporary facilities. Thus, according to the different colors and patterns on the CAD drawing, the space user can be identified easily.

Space Conflict Identification

The space demands for various activities are specified by site engineers and displayed on the CAD drawing. Combining space demands within the same time period reveals conflicts between various activities. This is similar to the combination of various design drawings, which identify physical space conflicts within the final design. During construction, the combination of space demands can help the engineer identify potential space conflicts. Fig. 5 shows the concept of space conflict identification.

In this study, space conflict is defined as more than one space demand claim on a specific available space during the same time period. Thus, when all of the space demands of various subcontractors are overlapped on the CAD drawing for a specific time period, space conflicts can be detected. Table 2 shows a compiled example of space demands for various subcontractors during different time periods.

Once a space conflict is detected, data regarding the affected activities as well as the size of the overlapped space are required for conflict analysis and resolution. The following variables are defined for subsequent analysis:

1. Interference space size—size of overlap between activities,
2. Interference space percentage (ISP)

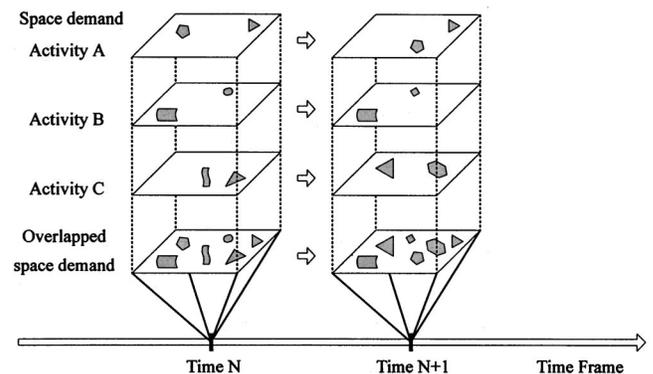


Fig. 5. Concept for identifying space conflicts

Table 2. Example of Space Conflict Identification

Conflict number	Activity	Task code	Space user	Type of space	Time overlap of conflicts	
					First Day (a.m.)	First Day (p.m.)
7-1	Reinforced steel	7-3	Reinforced steel labor	Working space	xxxxxxxxxx	—
	Plumbing	7-4	Plumbing labor	Working space	xxxxxxxxxx	—
7-2	Reinforced steel	7-3	Column	Storage space	—	xxxxxxxxxx
	Plumbing	7-4	Conduit	Storage space	—	xxxxxxxxxx

$$ISP = \frac{\text{interference space size}}{\text{original size}} \times 100\% \quad (1)$$

3. Interference duration—length of time for overlapped space demand, and
4. Interference duration percentage (IDP)

$$IDP = \frac{\text{interference duration}}{\text{original duration}} \times 100\% \quad (2)$$

Fig. 6 demonstrates an example of these variables.

Resolution Strategy

To overcome space conflicts, three resolution strategies are considered. The first strategy is to adjust the space demand, which changes the location of the space demand, or divide the original space demand into several smaller areas to eliminate space conflicts. This approach does not alter the original schedule, and if it is feasible, it minimizes the impact on the construction site. The second strategy adjusts the planned schedule to avoid space conflicts. Typical solutions for this strategy include adjusting the starting time of an activity, reducing the length of time for space requirements, or splitting the working time period. Typically, this approach delays the original schedule; however, a minimum delay is the decision criterion for space conflict resolution. The third strategy is a hybrid approach, which adjusts the space demand and scheduling sequence simultaneously. Thus, changing the quantity of space users or even the construction method may resolve space conflicts.

Criteria for Resolving Space Conflict

Once the strategy is established, criteria that determine the activity to be modified become essential. To resolve space conflicts, the characteristics for each involved activity must be analyzed. Hence, this research develops a series of criteria for analyzing conflicts characteristics and assists the engineer in deciding which activity requires adjustment.

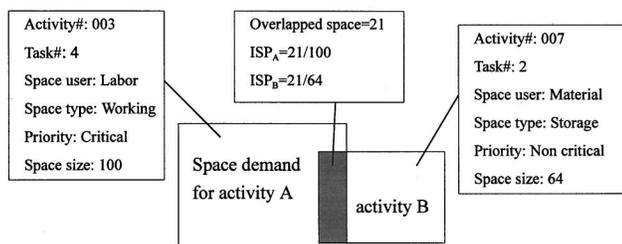


Fig. 6. Data example for overlapped space demand

1. Logical sequence between activities. If conflict is identified, the logical sequence between these activities is verified initially. If a logical sequence relationship exists, the space demand for successive activities must be adjusted.
2. Critical path. Activities on the critical path have the priority to claim space demand; other noncritical activities will be modified.
3. Space divisibility. If the space demand can be divided into several smaller areas, then the space conflict may be eliminated.
4. Location change. If the space demand, such as material storage, can be altered, then the space conflict may be eliminated.
5. Space size modification. If the space demand can be adjusted or decreased, i.e., constrained to a specific limit, the space conflict could be eliminated. However, the productivity of the adjusted activity may be affected.
6. Start time of conflicting space occupation. The start time of an activity to occupy a space could be a criterion for deciding which activity requires adjustment.
7. Length of occupancy time. The duration of occupancy could also be a criterion for deciding on the conflict resolution approach.

Despite the aforementioned criteria, additional factors may help to analyze and resolve the conflicts. These affiliate criteria include the size of the conflict, location of the conflict, duration of the conflict, and other specific characteristics of the conflicting tasks. This study also defines the ISP and IDP for further analyses and decision rules. Table 3 summarizes categories and criteria for resolving space conflicts.

Space Conflict Reidentification

Once the original conflicts are resolved, the whole process of conflict identification and resolution must be executed again to ensure that no further space conflicts have occurred due to the adjusted space allocation or schedule rearrangement. Generally, this process can be completed in a short period. However, if further conflicts occur continuously or trigger subsequent problems, then the resolution strategy may require modification. In this circumstance, rearranging space usage or the schedule may not solve all of the conflicts effectively. Hence, a hybrid approach, such as applying alternative construction methods, may be more effective.

Path Demand Verification

Although all of the space conflicts have been resolved, the space planning is not yet complete. The final step is to ensure that there is enough path space for all of the required laborers and equipment, and for material transportation. Therefore, a minimum path width and height were defined as follows:

Table 3. Categories of Criteria for Resolving Space Conflicts

Category	Major criteria	Affiliate criteria	
		Space Related	Time Related
Criteria	Logic sequence	Size of conflict	Duration of conflict
	Critical path	Size of conflict	Duration of conflict
	Space divisibility	Interference space percentage (ISP)	Interference duration percentage (IDP)
	Location change	Location of conflict	Specific characteristic of conflict tasks
	Size modification	Other related data or characteristics	—
	Start time of occupancy	Other related data or characteristics	—
	Length of occupancy time	Other related data or characteristics	—

$$\text{Minimum path width} = \max \left\{ \text{all activities} \left[\begin{array}{l} \min(\text{width for labor}) \\ \min(\text{width for equipment}) \\ \min(\text{width for labor/material}) \\ \min(\text{width for equipment/material}) \end{array} \right] \right\} \quad (3)$$

$$\text{Minimum path height} = \max \left\{ \text{all activities} \left[\begin{array}{l} \min(\text{height for labor}) \\ \min(\text{height for equipment}) \\ \min(\text{height for labor/material}) \\ \min(\text{height for equipment/material}) \end{array} \right] \right\} \quad (4)$$

The minimum path width and height can be derived from the above equations to examine if the path demands can be satisfied. Items that require examination include

1. Available path from the entrance to each working area,
2. Available path from the entrance to each storage area,
3. Available path from each working area to the associated storage area,
4. Available path from each working area to the other working areas with the same activity, and
5. Available path from the current storage areas to the next stage storage areas.

When all path requirements are satisfied, the space planning is complete. Otherwise, appropriate adjustments must be made to eliminate insufficient path demands. However, if path demands remain unsatisfied, the aforementioned process of space conflict resolution must be reexecuted for an alternative feasible solution.

Case Illustration

A typical 12-story reinforced concrete residential building is used to demonstrate the identification and resolution of space conflicts via the decision criteria. This jobsite is approximately 1,000 m², with a total floor area of 5,775 m². The space planning for each floor requires various space requirements for the survey, reinforcing steel, plumbing and electrical, scaffold, formwork, concrete, and management. Fig. 7 displays the combined CAD drawings from the initial schedule as well as the space requirements of all subcontractors, which reveal many space conflicts.

To resolve the space conflicts, the decision support system initially compiles all of these conflicts according to the space users, type of space, duration of the conflicts, location/size of the conflicts, as well as other related data of the competing activities. As mentioned previously, a list of conflicts is then established (Table 2). Table 4 lists the characteristics for space conflict 7-1 (seventh floor, steel workers versus plumbing workers). According to the developed criteria for conflict analyses and resolution, the procedure for resolving space conflict 7-1 is as follows:

- Step 1—Logical sequence. The column bars erection must be completed before the plumbing work, and the column ribs have to be done after the plumbing work is finished. This criterion clearly defines the working sequence for steel workers and plumbing workers.
- Step 2—critical path. Both the steel erection and plumbing works of these columns are on the critical path of the project. This criterion cannot distinguish the priorities for the steel workers and plumbing workers.
- Step 3—space divisibility. Both of the working spaces needed for steel erection and plumbing are around the permanent location of the columns to be erected; therefore, the required working space cannot be divided in this case, either.
- Step 4—location change. From Fig. 7, it can be found that there are two shear walls (elevator room) and nine columns (edges of the building) that will cause space conflicts for steel workers and plumbing workers. Although the working space of each column is fixed and cannot be changed, the overall working location can be adjusted by splitting the workers up to work on a couple columns at a time. For example, the steel workers can start the column bars erection of the two columns on the east side. When the first two columns are done, the steel workers can then move to the next two columns in the center area while the plumbing workers can start to work on the first two columns. In this approach, this criterion may provide a feasible solution to this space conflict.
- Step 5—size modification. In this case, adjusting the size of the space requirements for both steel workers and plumbing workers is infeasible, since the floor area is very limited. This criterion does not help in this case.
- Step 6—start time of occupancy. Both steel workers and plumbing workers are originally scheduled to start their jobs at 8 a.m. However, according to the resolving criterion in step 1, the steel workers must erect the column bars first. As a result, the start time of the plumbing workers must be delayed for space conflict resolution.

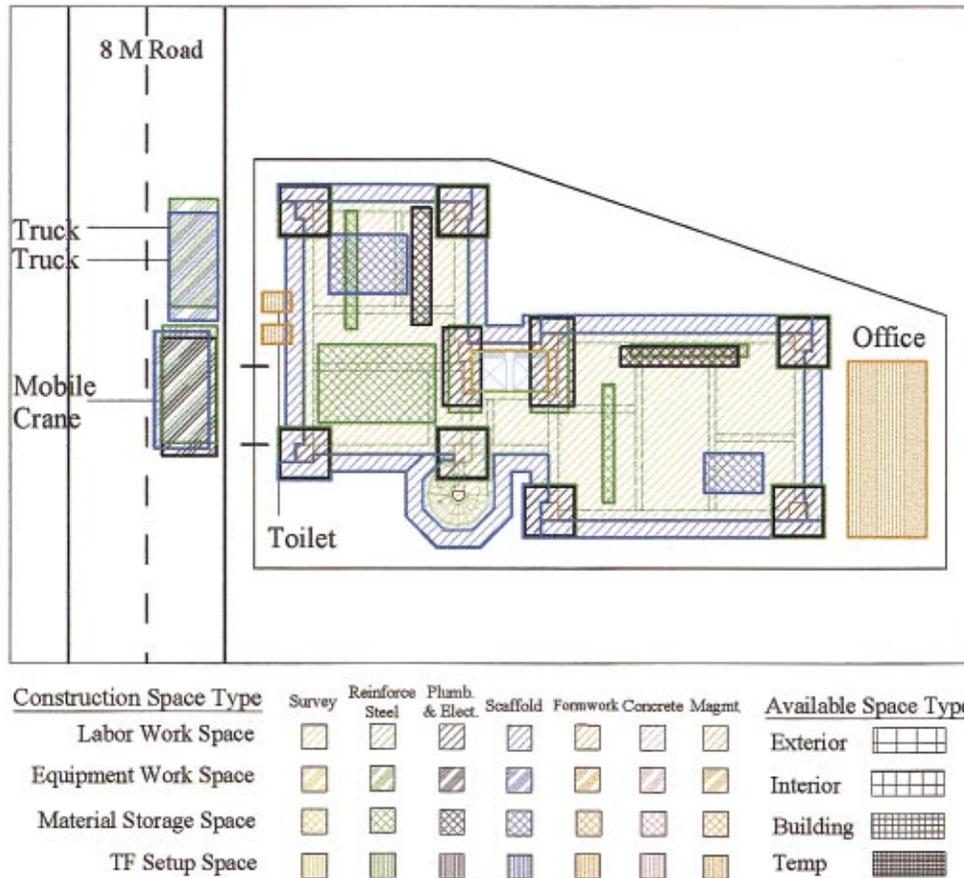


Fig. 7. (Color) Conflicts identification for all subcontractors

- Step 7—length of occupancy time. Both steel workers and plumbing workers need 4 h to complete their own task. Unless the human-power is increased, the length of occupancy time cannot be reduced. On the other hand, based on the resolving criterion in step 6, the finish time of the plumbing task will be delayed.

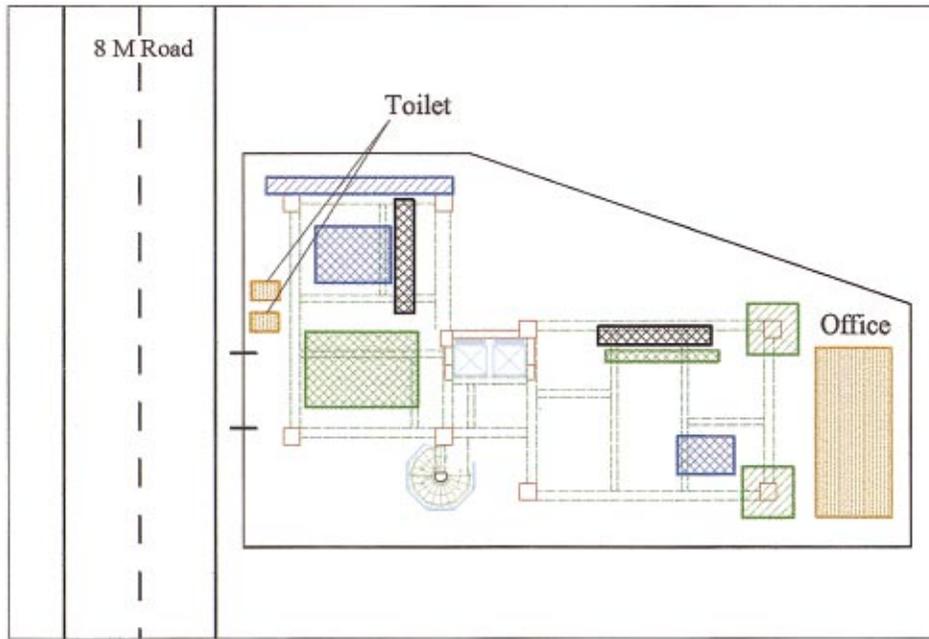
According to the above step-by-step analyses of the criteria, a more suitable approach to resolve this problem is to adjust the planned schedule to avoid the space conflicts. Figs. 8 and 9 display that by splitting the reinforcing steel tasks of the columns to be erected, the conflicts between reinforcing steel and plumbing/electrical can be eliminated. That is, steel workers must install the column bars first; then the plumbing/electrical workers have to follow the column bars installation with pipe installation. Finally, the steel workers must complete rib bar erection for the formwork workers to follow on. Since the start time of the plumbing/

electrical workers is delayed for about 2 h, while waiting for the steel workers to install the column bars, the finish time of the plumbing/electrical work is thus delayed. Consequently, the rib bar completion is also delayed. Originally, the formwork subcontractor was scheduled to begin at 2 p.m. However, due to the space conflicts and proposed resolution, the formwork workers also must delay their starting time.

After the space conflict between the steel workers and plumbing/electrical workers is resolved, the decision support system examines if there are other subsequent unsolved conflicts. Although Fig. 9 displays a dummy conflict between the scaffold and temporary toilet, no actual space conflict exists. That is, the toilet did not interfere with the scaffold on the seventh floor because it was on the ground level. When all of the other space conflicts are resolved and no further conflicts occur, the system will then verify if the path requirements are satisfied.

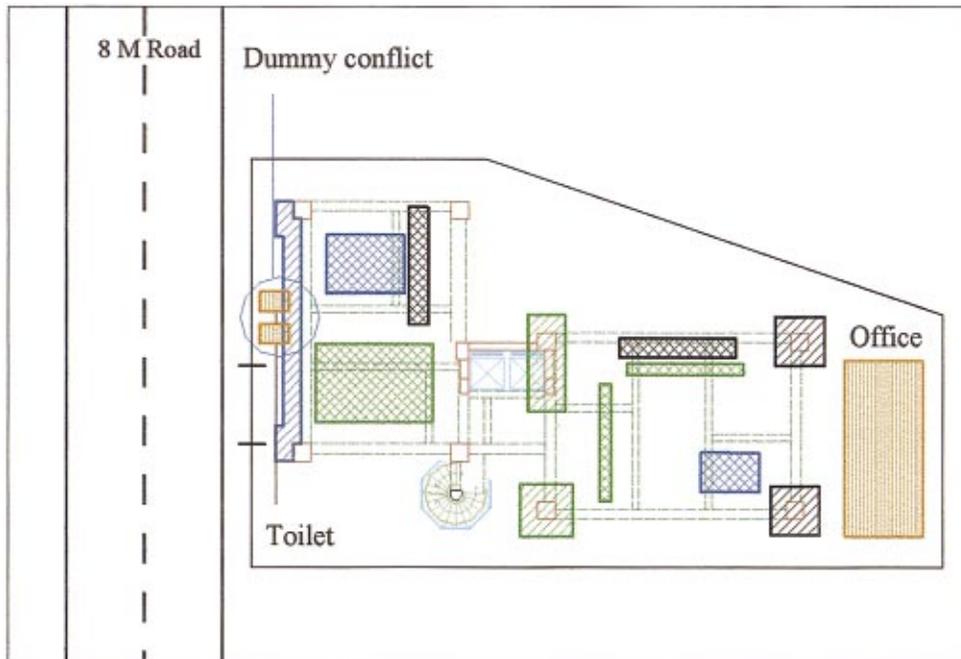
Table 4. Characteristics for Conflict 7-1 (Steel Workers versus Plumbing Workers)

Major criteria	Working space	
	Steel Workers	Plumbing Workers
Logic sequence	Column bars erection→plumbing→ribs erection	Column bars erection→plumbing→ribs erection
Critical path	Yes	Yes
Space divisibility	No	No
Location change	No	No
Size modification	No	No
Start time of occupancy	First day, 8 a.m.	First day, 8 a.m.
Length of occupancy time	4 h	4 h



Construction Space Type	Survey	Reinforce Steel	Plumb. & Elect.	Scaffold	Formwork	Concrete	Magnt	Available Space Type
Labor Work Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Exterior [Pattern]
Equipment Work Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Interior [Pattern]
Material Storage Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Building [Pattern]
TF Setup Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Temp [Pattern]

Fig. 8. (Color) Conflict resolution between reinforcing steel and plumbing (8 a.m.)



Construction Space Type	Survey	Reinforce Steel	Plumb. & Elect.	Scaffold	Formwork	Concrete	Magnt	Available Space Type
Labor Work Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Exterior [Pattern]
Equipment Work Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Interior [Pattern]
Material Storage Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Building [Pattern]
TF Setup Space	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	[Pattern]	Temp [Pattern]

Fig. 9. (Color) Conflict resolution between reinforcing steel and plumbing (10 a.m.)

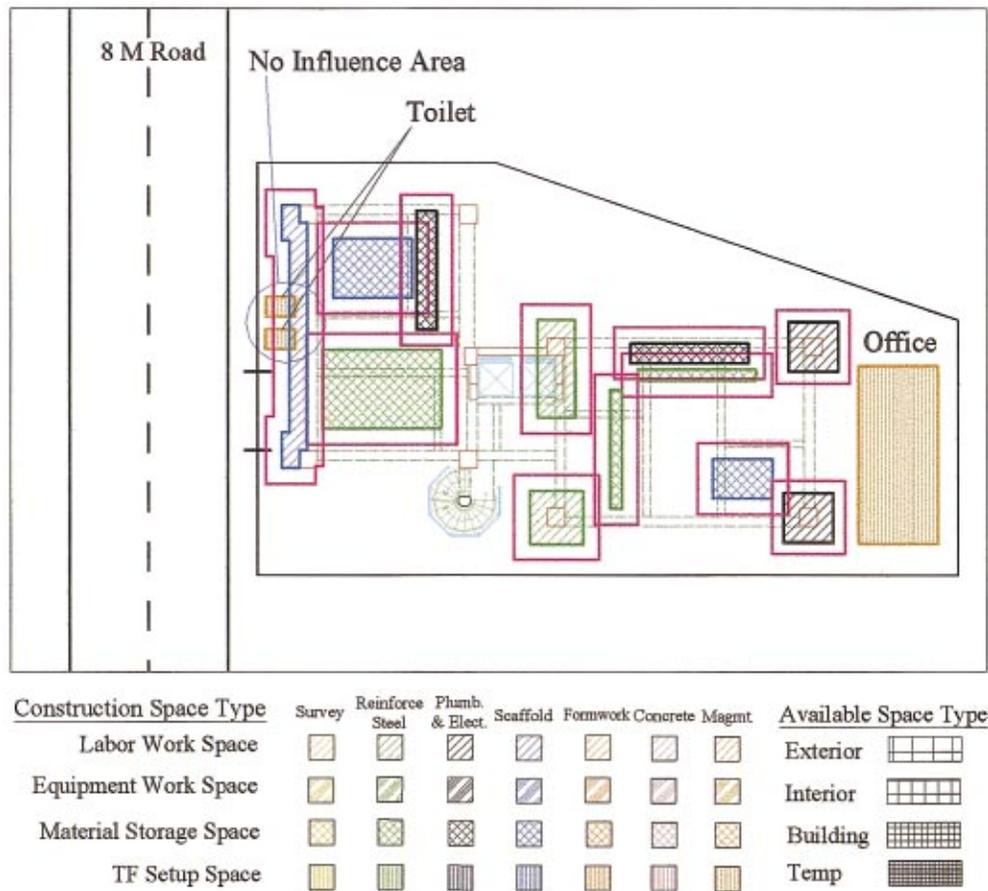


Fig. 10. (Color) Path requirements verification for various subcontractors

According to Eqs. (3) and (4), the minimum path width and height for this particular case can be obtained. In the illustrated case, the material transportation is done manually without equipment. The path width (steel worker/rebar, plumbing worker/pipe, and carpenter/formwork) does not require extra space. A 1 m path width will satisfy all of the associated activities. On the other hand, all of the tasks are executed on top of the completed floor; thus, there are no path height constraints. The developed system adopts a 1 m borderline for checking all of the path width requirements. Fig. 10 illustrates the result of the path requirement verification of this case. Since all of the path requirements are also satisfied, the space planning process is complete. The decision support system will then forward these data to the schedule software and update the rearranged schedule.

Discussion and Conclusions

Numerous workers, equipment, material, temporary facilities, and permanent structures share limited space during construction. Since space constraints may affect the moving path and productivity, it is essential to organize the available space efficiently, such that the space conflicts are minimized. The space availability on a site may change due to time and scheduling arrangements. Thus, site layout/space planning has been a significant and complex problem for construction engineers. However, the construction industry has lacked efficient and systematic approaches for site layout and space planning. Therefore, when faced with a space conflict problem, many engineers rely on personal experi-

ence. However, this heuristic approach fails to consider that space availability may change with time and schedule, the possibility of alternative space, or the productivity loss due to path interference and space constraints.

This study established a procedure and criteria for identifying and resolving space conflicts. Previous researchers resolved this problem based on minimal traveling distance or cost between temporary facilities. However, this solution applies only to the transportation optimization process, and not directly to work optimization, nor the shortest working period. Alternatively, this study considered space availability due to time and schedule, productivity loss due to path interference and space constraints, as well as the possibility of alternative space for conflict resolution and optimal usage. Herein, the CAD system was integrated with schedule software for the dynamic identification of space conflicts on the jobsite for various subcontractors. Follow-up supplemental decision criteria were then provided for conflict analysis and resolution. Furthermore, a prototype decision support system that combined the criteria was developed to solve this significant and complex problem more efficiently and precisely. Finally, a case study demonstrated the use and development of this system, which will be very helpful to engineers and project managers.

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