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# SCHEDULE GENERATION: A FUZZY REPRESENTATION OF TRADE INTERACTION CONSTRAINTS

C. William Ibbs, T.C. Chang and Diego Echeverry

Dept. of Civil Engineering
University of California
Berkeley, CA 94720

## ABSTRACT

Automated generation of project schedule templates depends upon geometric-spatial constraints, both of the constructed facility itself and of worker interaction. Several researchers have explored the design-based spatial building layout problem; that is, the building's physical and topological characteristics. Our previous research examined this as well as the work process constraints that arise when laborers have to compete for the same physical space at the same time to work. These limitations arise when humans literally compete for the same physical space; or when their work processes might be injurious or disruptive to others nearby.

This paper addresses a representation model to handle these nebulous, critical interactions. A fuzzy logic knowledge-based approach is described. Principal focus is on the tenant-improvement trades of drywall installation and wall covering. Links to an existing fuzzy expert system for resource allocation are described.

## 1.0 INTRODUCTION

Considerable work is occurring these days in using knowledge based systems technology to build automated construction schedule generators [Echeverry 91; Kartam 90; Navinchandra 88]. The goal of this general research field is to build software tools that will provide "schedule templates" to relieve project planners of routine project scheduling details. The hope is that given a template that reflects the project's details, the planner can apply his or her more creative talents to those aspects of the problem more demanding of human attention.

To date most of this research has focused on the physical relationships among the building components. Semantic relationships such as "connected to" and "supported by" are representative. A key finding of Echeverry's work is that there are activity dependency relationships beyond these physical factors though. In particular we identified *Trade Interaction*, *Regulatory Codes* and *Path Interference* as being three other general families of relationships. In this paper we explore the Trade Interaction aspects using fuzzy logic concepts to model the associated uncertainties.

## 2.0 TRADE INTERACTION RELATIONSHIPS

A variety of sub-relationships comprise the Trade Interaction constraint family. We chose to explore the Trade Interaction factor first, because in our judgement it was more of unknown than the other two. We also chose to focus on tenant improvement work because that is we have some experience. It also is critical to mid-rise building construction which is our focus.

## 2.1 Space Competition

Following the traditional knowledge-based approach, the space competition problem may be expressed in the form of a rule:

**If** one crew (or piece of equipment) occupies a space
**then** the space is unavailable for any other crew (equipment).

This is obviously a binary expression; that is, a space is either occupied or not occupied, no matter how large the space is. This binary method restricts our ability to describe a situation that is, in fact, not a crisp event. As a result, the rule does not convey complete information to the users. Accuracy is lost when the rule is entered into a knowledge base.

Theoretically, we could divide the space into smaller and smaller spaces such that each unit could eventually accommodate one crew. Under these conditions the binary or true/false method would work. This is impractical though because the crew size varies and the use of the space is time dependent.

Our approach is to consider the crowdedness of a space as a key to resolve the space competition problem. If we can measure the degree of crowdedness, the problem of space constraint can be controlled. The following rule is, for example, a better description of the problem:

**If** the degree of crowdedness in the work space for activity j is high
**then** the productivity of activity j will be greatly affected.

In general, fuzzy logic can be used to establish the relationship between degree of crowdedness and degree of productivity affected [Zadeh 75]. Once the degree of productivity affected is known, the impacts on activity duration and cost can be evaluated accordingly. Any impact on activity duration can be evaluated using the concept of penalty factor introduced in [Chang 87; Chang 90]. That is, by using an empirical equation such as:

$$New\ Duration = \frac{Old\ Duration}{1 - K\ P_c} \qquad (1)$$

Where K is a user defined subjective factor (a heuristic number) and $P_c$ is the degree of productivity affected by the crowdedness. The disadvantage of this equation is that the definition of K may be controversial. For example, let $K = 0.05$. Then, when the degree of productivity is absolutely high (i.e., $P_c = 1.0$) a new duration which equals twice of the old duration can be obtained using Eq. (1). This is purely heuristic or empirical, and may not be agreeable to different users.

An alternative to measure the impact on activity duration is to use fuzzy production rule [Chang 87; Chang 88]. Then fuzzy logic can be applied on the rule. The following is an example:

**If** the degree of productivity affected is high for activity j
**then** the duration of activity j shall be extended with a factor of about 0.7.

This approach depends on expert experience (heuristic or empirical), too.

As a matter of fact, we may not want to assign too many trades in the same work space because that may cause too much congestion. Thus, to control the crowdedness, we can set up a criterion such as:

**If** the degree of crowdedness of the work space reaches high when the first n activities with higher priority have been scheduled to be performed in the same space
**then** delay the other activities with lower priority until the crowdedness is low.

Now, the problem is how can we measure the degree of crowdedness. Our approach is to treat space as a resource. The area of a specific space can be estimated using a CAD database or by reviewing the plans and specifications of a project. The estimated area is the available work space as shown in Figure 1. And, an early-start profile (ESP) of the total space required for all candidate activities in a given time frame can be generated from a project schedule database assuming the schedule has been established. An example of the ESP is shown in Figure 1 where the shaded area indicates the work space is crowded. Figure 1 also shows the very crowded (degree of crowdedness is high) and more or less crowded (degree of crowdedness is moderate) time periods. The 30% line, that is the maximum allowed deviation, is a heuristic and the scale for the degree of crowdedness is in terms of fuzzy concepts.

The entire procedure for controlling the space constraint is demonstrated by Figure 2.

2.2 Unsafe Environment Effects

The impact of unsafe environment effects can be measured in terms of "degree of safety". The "degree of safety" can be subjectively evaluated by a safety engineer or an experienced field engineer. The evaluation can be done using qualitative terms such as high, moderate, or low. The qualitative terms can be then interpreted into fuzzy sets, and fuzzy logic can be applied on them.

The evaluation of the impact on productivity due to the degree of safety can rely on fuzzy production rules from experts. For example, the following rule can be a useful rule in determining the impact:

**If** the degree of safety in the work space for activity j not very high
**then** the productivity of activity j will be seriously affected.

The subjectively determined degree of safety can now be applied to the above rule using fuzzy logic to find the degree of impact. As before, the process of using fuzzy logic is described in [Chang 88].

2.3 Interaction of Space Competition and Unsafe Environment

Impacts on productivity due to crowdedness (space competition) and unsafe environment are two separate factors. In some circumstances, both factors may exist at the same time in the same work space. This causes a much worse condition in the available work space. The interaction between these two factors must be considered.

Under this situation, we have two fuzzy production rules for the two factors. In general, they have the following forms:

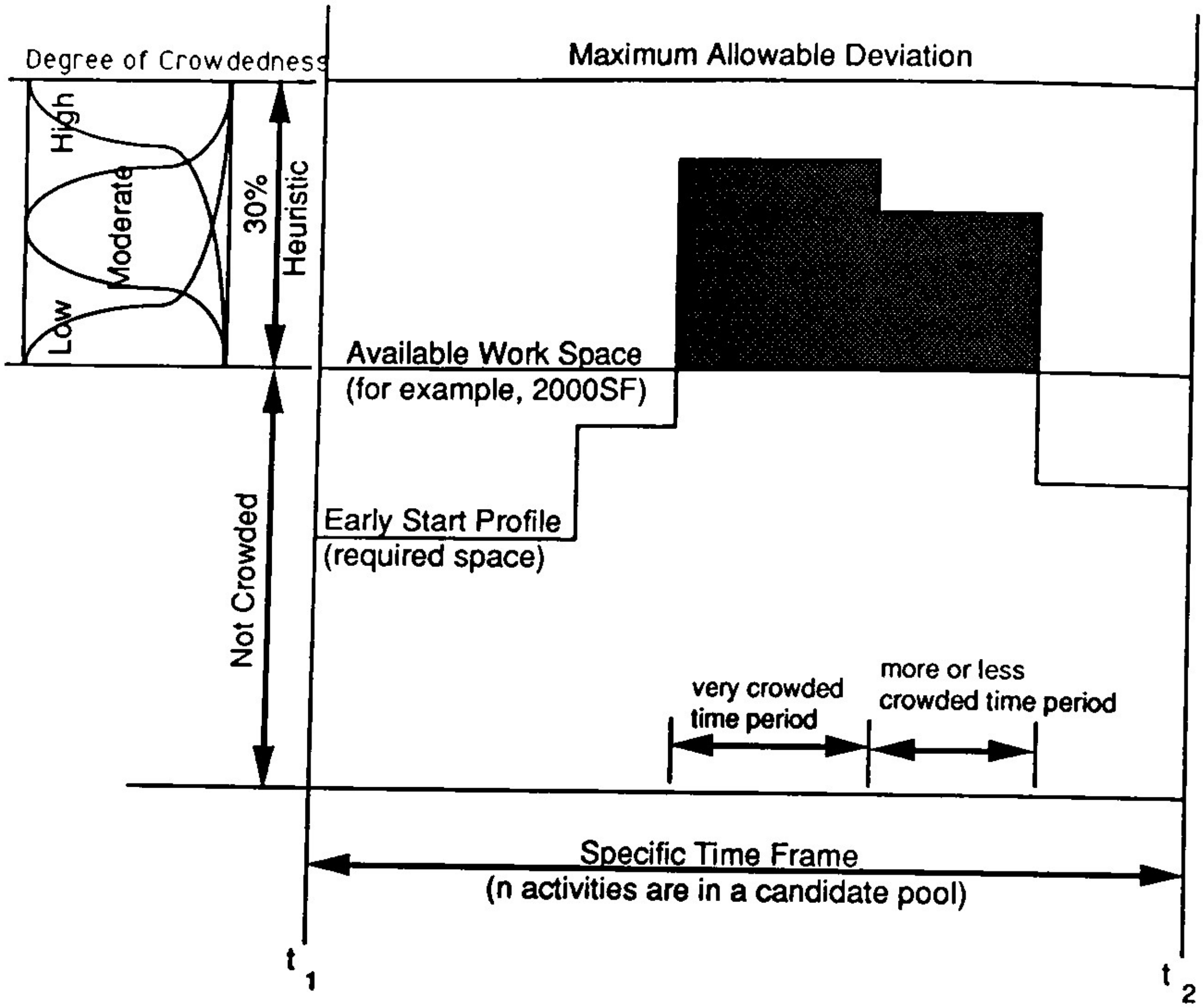


Figure 1: Work Space "Profile"

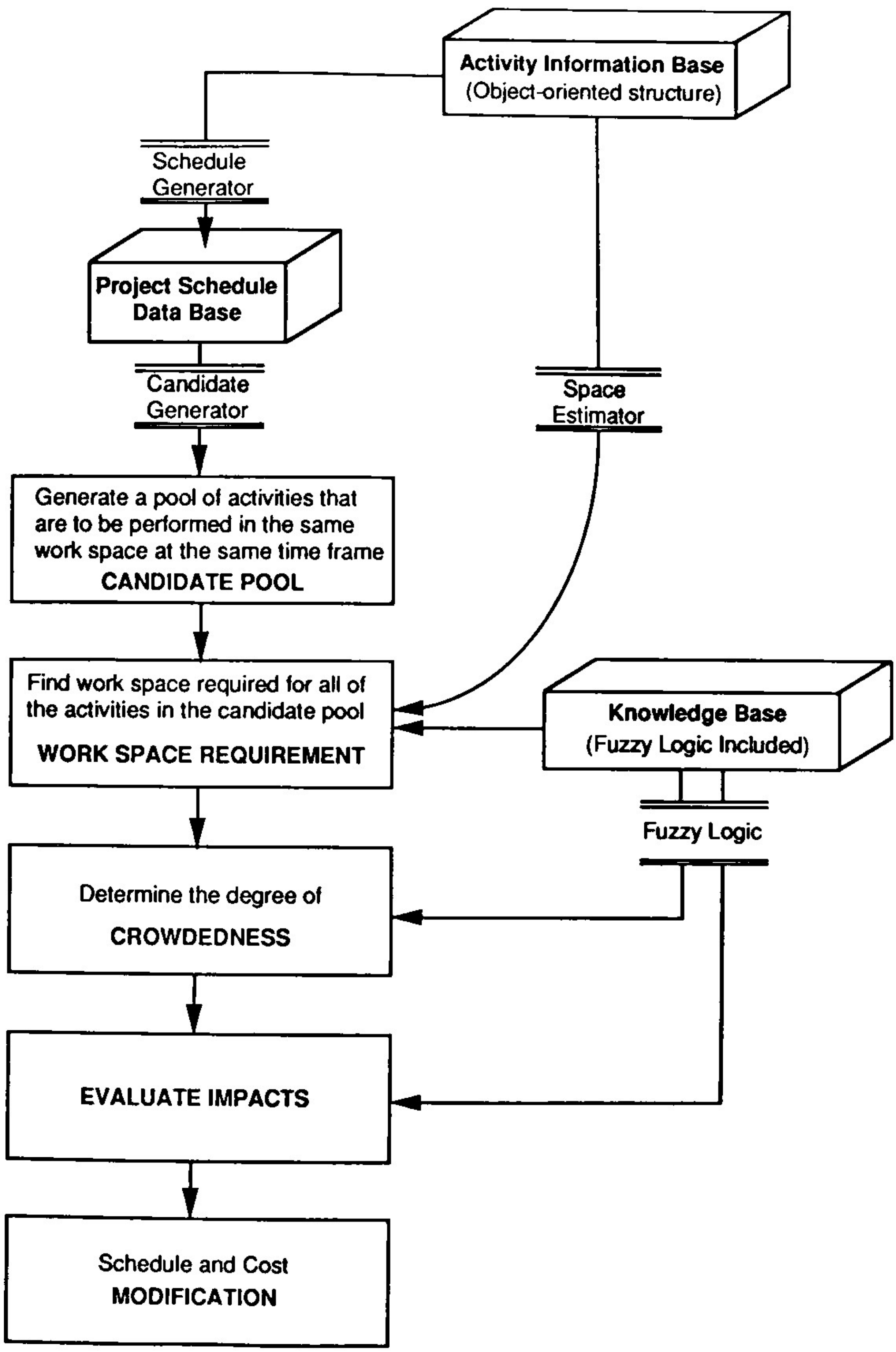


**Figure 2: Procedure for Controlling Space Constraint**

$$If\ X_1\ is\ A_1,\ then\ Y\ is\ B_1 \qquad (2)$$

$$If\ X_2\ is\ A_2,\ then\ Y\ is\ B_2 \qquad (3)$$

Where $X_1$ is the degree of crowdedness, $X_2$ is the degree of safety, Y is the degree of productivity impacted, $A_1$ "high", $B_1$ can be "great", $A_2$ can be "not very high", and $B_2$ can be "serious". As discussed in Section 2.1, the degree of crowdedness can be obtained using the resource profile approach. Let's assume the degree of crowdedness for a particular works space is $A_1^*$ (for example, $A_1^*$ = moderate). And, as mentioned in Section 2.2, the degree of safety can be subjectively evaluated. Furthermore, assume the degree of safety for the particular work space is $A_2^*$ (for example, $A_2^*$ = low). Now, with $A_1^*$ and $A_2^*$ we can apply the Fuzzy Modus Ponens inference rule of Fuzzy logic [Chang 88] to the fuzzy production rules as shown in (2) and (3). Denote denote the conclusions as $B_1^*$ and $B_2^*$, respectively. $B_1^*$ and $B_2^*$ are two separate results considering the two separate factors -- degree of crowdedness and degree of safety. We need to combine the two results to a final result which can represent the interaction of the existence of the two factors. We propose two approaches to this issue.

The first approach is to use a heuristic equation to determine the final effect of $B_1^*$ and $B_2^*$. The fuzzy mean [Chang 87; Chang 88] of $B_1^*$ and $B_2^*$ can be determined as follows:

$$M_S(B_i^*) = \frac{\sum_{u \in U} u \cdot \mu_{B_i}(u)}{\sum_{u \in U} \mu_{B_i}(u)} \qquad (4)$$

Where i = 1,2; $\mu B_i(u)$ is the membership grade of $B_i^*$; and u is a member in the universe of $B_i^*$. With $M_S(B_1^*)$ and $M_S(B_2^*)$, the final result can be heuristically estimated as follows:

Productivity impacted =

$$M_S(B_1^*) + M_S(B_2^*) - M_S(B_1^*) \cdot M_S(B_2^*) \qquad (5)$$

The second approach is to gather an expert's opinion and set rules such as:

If the degree of crowdedness is high and the degree of safety is low then the combined effect is extremely high.

and

If the degree of crowdedness is high and the degree of safety is high then the combined effect is high.

With these fuzzy production rules, fuzzy logic can be applied again to determine the final result, as previously described.

## 3.0 SUMMARY AND CONCLUSIONS

The intent of this paper was to briefly describe our current work on the Trade Interaction relationships that impact schedule activity precedence and duration. In particular we examined "space competition" and "unsafe environmental effects" separately and interactively. Because there is considerable uncertainty associated with these various sub-factors, we modelled the process with fuzzy logic. Though traditional probabilistic approaches might have been used, the lack of crispness in the boundary conditions led us to conclude that this was a proper approach.

## 4.0 REFERENCES


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