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IMPACT OF STOCHASTIC TIME WINDOWS IN PLANNING FOR CONSTRUCTION PROJECTS

Serhii Naumets[1]

[1]Department of Civil and Environmental Eng., University of Alberta, Edmonton, AB, CANADA

ABSTRACT

In my thesis, I attempt to rethink the foundation of conventional construction engineering planning. I developed a new cost analysis algorithm as an alternative to the traditional time-cost trade-off approach. The new algorithm was built upon the existing time-cost trade-off knowledge and tailored to the time-window planning method. The main difference from the traditional approach lay in pivoting the focus from global optimum to emphasizing planning of alternative execution methods and their ranking. To accommodate the pivot, I framed a so-called reward function as an indicator of how favorable each alternative execution method is in the context of total project time and cost. It was achieved by simulating all possible scenarios of a project plan and deriving the reward function for each alternative. The resulting output of the simulation gives an insight into which activities have the most impact on the project time and cost and to what extent.

1 THESIS PROBLEM

Albert Hirschman (1967) formulated a concept of a "Hiding Hand" in which he stated that "since we necessarily underestimate our creativity, it is desirable that we underestimate to a roughly similar extent the difficulties of the tasks we face so as to be tricked by these two offsetting underestimates into undertaking tasks that we can, but otherwise would not dare, tackle." He argued that many construction projects often face such difficulties that had planners known them in advance, they would probably never have approached these projects in the first place. The former San Francisco mayor, Ed Lee, justified the cost overruns of the undertaking ventures during his two terms, such as Transbay Terminal, Central Subway, and Bay Bridge, in the following words: "In the world of civic projects, the first budget is really just a down payment. If people knew the real cost from the start, nothing would ever be approved" (Brown 2013).

Bent Flyvbjerg and his research team out of the University of Oxford gathered a database consisting of cost and time estimates for more than 16,000 projects across more than 20 different fields in 136 countries and found that nine out of ten such estimates are over budget and over time with an average cost overrun of 62% (Flyvbjerg 2014). In their recent book Flyvbjerg and Gardner (2023) considered many fallacies that lead to cost and time overruns, one of which is over-optimistic master planning. The findings of a sociological study by Griffin et al. (1990) suggest that when making a prediction estimate about the worth or timespan of events related to themselves or others, people routinely leave very little room for uncertainties. In other words, we assume the best-case scenario as an average prediction. On the other hand, the same authors note that when subjects are presented with alternatives they are obliged to consider, their awareness of the possibility of error increases (Griffin et al. 1990). Let's consider the last two findings and the fact that in the construction field, the master plan and estimate provide the contractual baseline for time and cost control. We can argue that regardless of how successful the construction execution of a project is, the time and cost will almost always exceed beyond the over-optimistic baseline. As Hirschman suggested, unforeseen difficulties are a common challenge in construction projects, often leading to cost and time overruns (1967). This issue is exacerbated by traditional planning methods like the Critical Path Method, which typically rely on over-optimistic estimates that fail to account for variability and uncertainty in project conditions. My research addresses this gap by introducing a planning approach that integrates uncertainties into project scheduling more effectively. I extended the concept of project Time-Cost Trade-off in construction management by providing an analytical framework to assess activity method alternatives based on the results of Monte Carlo simulation.

2 METHODS

A scheduling method I developed uses a simulation algorithm incorporating time windows induced by the natural environment. As an output, I extract an analytically derived metric for each alternative construction option, so-called "reward." The greater the reward, the more favorable the alternative in terms of total construction cost and duration. Consequently, the algorithm sheds light on the most cost-effective project planning scenario, revealing activity alternatives with the highest impact on project cost and time reduction. The proposed planning method integrates time-window constraints developed in the first stage of my research (Naumets et al. 2022).

As an extension, I propose stochastic time-windows, which are defined as a distribution representing time-window boundaries. For example, a Winter Road time window in the north of Canada that imposes restrictions on when materials and workforce can be moved by land to and from remote job site, as well as the period when all the water bodies are frozen, on average, takes place between December 20 to April 1. This information should be represented as a distribution based on historical weather data for a Monte Carlo simulation algorithm. For illustration, the project described in (Naumets et al. 2022) had 15 major bridge-building activities with two to three alternative execution methods each, totalling 2,125,764 possible project scenarios. It also had two time windows over the two-year period that started and stopped at varying dates with a rough range of occurrence of about 20 days each. Assuming that these time windows every year start and end on different dates, the number of possible scenarios in the presented study would increase to 2,125,764 x 4 x 20 = 170,061,120. Considering that most construction projects have many more activities, the number of all possible scenarios could become astronomical and impossible to simulate. For example, if the above bridge project had just fifty activities with three alternatives each and we kept the simplified assumption about stochastic time windows, the number of possible scenarios would increase to 3^{50} x 4 x 20 = 57,431,839,015,348,200,000,000,000. The major limiting factor in this case would be storing all the enumerated simulated data in the computer's RAM before making the final calculations.

As the final enhancement of my planning algorithm, I propose a Monte Carlo construction scheduling simulation incorporating stochastic time-windows with short-term memory computing. Instead of storing all the scheduling data from every iteration, the algorithm only remembers the reward function for every execution method and the number of their occurrences. This enhancement solves the algorithm's RAM limitation. To tackle the exponential growth of possible scenarios, I analyze different sampling strategies, comparing the results of Enumerated simulation (all possible scenarios) and Monte Carlo simulation (various sample sizes starting from as little as 0.001% of enumeration.) This comparison will indicate how many Monta Carlo runs out of all possible scenarios are necessary to compute meaningful reward functions.

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