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Resource scheduling and planning for tunneling with a new resource model of the Decision Aids for Tunneling (DAT)

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ABSTRACT

Resource scheduling and planning are the strategies required to determine the sequence of activities and resource allocation during tunnel construction. Resource scheduling and planning have been implemented in a new resource model of the Decision Aids for Tunneling (DAT), which are a computer based tool used to simulate tunnel construction. Tunneling plans obtained with the new resource model of the DAT take into account the technical precedence of activities, the resource/space availability, the dynamic status of the process, and the work continuity. In particular, the new resource model of the DAT can provide the optimal tunneling plan, which produces the shortest construction time and the smallest construction cost, and satisfies the special characteristics of tunnel construction such as excavation methods, distance requirements between the headings, and preempting activities (e.g., blasting).

The paper attempts to contribute to both theory and practice: Optimization of the construction process considering time, cost and resources is particularly complicated in tunneling where activities and resource availability have to be appropriately sequenced and interference has to be avoided. The paper addresses this fundamental problem with the development of different schematic tunneling plans that consider the relevant activities and optimizes them with regard to overall cost and time, also considering uncertainties. Equally important is to make the theoretical development practically useable. This is done through implementation of the resource optimization in the DAT and, very importantly, by demonstrating the practical use with an application to a real tunnel case.

1. Introduction

The Decision Aids for Tunneling (DAT) are a computer based method with which distributions of tunnel construction time and cost as well as required and produced resources can be estimated considering uncertainties in geologic conditions, construction processes and resources (e.g. Einstein, 2002). The results of the DAT in turn can be used for various decision making processes. One of the notable recent developments of the DAT is the implementation of a resource management model with which resource usage and -flows during tunnel construction can be modeled. The DAT essentially consist of three modules called "geology module", "construction module" and "resource module". The resource module of the DAT uses the resource model to represents resource usage and –flows during tunnel construction. The core computer code of the DAT to perform the simulations is C/C++, and the graphical user interface and the resource model in the DAT are programmed in JAVA.

From the point of view of simulation strategy, the DAT can be categorized as an activity-based model. In an activity-based model, simulation parameters such as those characterizing resources, move from activity to activity during the simulation. Allocating a resource to a successor may involve decisions depending on the amount of resources available for the successors, and the number of successors that demand the same resources. If the same resources are required by multiple immediate successors, and the amount of resources is limited, selecting a recipient is important because the decision may affect part of or even the entire process. In this regard, resource scheduling and planning are crucial to the success of a project.

The resource model of the DAT that existed up to now had, however, several drawbacks and limitations. The scheduling and planning for resource allocation and -flows satisfied the technical constraints (e.g., technical precedence of the activities) and resource constraints (e.g., resource availability) while they did not guarantee the optimal resource allocation to complete the projects within schedule and budget. In dealing with resource allocation, the DAT set only the predefined heuristic rules for prioritizing activities, which may result in resource overshooting and

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process interruptions. Considering these shortcomings, a new resource model for the DAT was developed to overcome the identified problems and implement optimal resource scheduling and planning features (Min, 2008).

This paper first presents problems and limitations of the previous/current resource models of the DAT and of other construction simulation tools for resource modeling. This is followed by a discussion of possible methodologies and solutions to overcome the identified problems and limitations. The major improvements and the implementation of the new resource model are also presented. The final part of the paper demonstrates the new resource model with the application to a road tunnel project, which includes a comparative analysis among different approaches for resource scheduling and planning.

2. Resource modeling for tunneling

2.1. Introductory comments on resource modeling

A resource model for tunneling needs to be designed to represent and implement some fundamental concepts (Halabe, 1995):

- The model needs to represent various types, quantities and properties of resources that may affect the sequence of activities.
- The model needs to control construction processes considering types, quantities and properties of resources.
- The model needs to represent resource flow by associating resource availability, resource production, and consumption with the tunneling activities.
- The model needs to represent the characteristics of the resource flow, which include storing, queuing, sharing and competing of resources.
- The model needs to track the resources used and produced to identify the critical resources and activities.

2.2. Current resource model of DAT

The main features and algorithms used for the resource model of the DAT that existed up to now (called current resource model in the following) are based on developments by Halabe (1995) and Marzer (2002). In addition to having the main features and fundamental concepts required for resource modeling listed above, the current resource model of the DAT has the following capabilities:

- Resource dependency on ground conditions and location can be recognized.
- Performance of different process alternatives with regard to production and utilization of resources as well as operational efficiency can be considered by the model.
- Predefined heuristic rules are used for resource allocation (e.g., first-come–first-serve).
- Calendars are used to keep track of real calendar dates, and specify days-off, delays and different working schedules of the activities.

Nevertheless, the current resource model of the DAT has the limitations pointed out earlier (Section 1).

2.3. Resource modeling in other construction simulation tools

Several other construction-oriented simulation tools and their resource modeling have been reviewed and compared with the current resource modeling in the DAT (Min, 2008).

These other construction simulation tools include CYCLONE which models a process as a series of work cycles with a network of graphical symbols (Halpin and Woodhead, 1976, 1980); INSIGHT (Paulson, 1978), and RESQUE (Chang, 1986), which are two significant further developments of CYCLONE; COOPS (Liu, 1991), and CIPROS (Odeh, 1992); which are two conceptual and functional extensions of RESQUE; STROBOSCOPE which is a general-purpose simulation programming language used for the simulation of processes common to construction engineering (Marinez, 1996); RBM (Shi and AbouRizk, 1997) and LBS (Oloufa and Ikeda, 1997); and Symphony.NET (Hajjar and AbouRizk, 2002).

Compared to the current resource model of the DAT, some limitations in addressing resource handling and management identified in the other simulation tools or programming languages are as follows:

- The uncertainty in geology is not considered and hence all construction processes have to be performed for fixed geologic conditions.
- The uncertainty in the amount of resources consumed and produced from the activities is not considered in most other simulation tools except for STROBOSCOPE.
- Many of these simulation tools can handle only a small portion of a project instead of the project as a whole except for STROBOSCOPE and Symphony.NET. Therefore, they can be used for very specific tasks or operations, only, and for a project with a short duration.
- Many of these simulation tools cannot handle projects on a real-time basis since they can only model a particular process of a project instead of the overall project.
- Many of these simulation tools cannot model the construction processes at the necessary level of detail required by process planning, and cannot easily model the multiple resource requirements and dynamic complexity of construction processes except for STROBOSCOPE.
- Many of these simulation tools cannot recognize and represent resource dependency on ground conditions and location.
- Many of these simulation tools cannot handle different types of delays occurring in the construction processes, such as delays due to maintenance/inspection, equipment breakdown or holidays, and delays caused by ground conditions and/or locations of the tunnels.
- The users may have to learn the corresponding simulation languages (e.g., STROBOSCOPE).

There are also other recently developed simulation tools for resource modeling, which are commercially available such as CPM-based scheduling application (e.g., Primavera, Microsoft Project). However, CPM becomes convoluted if the schedule is resource-constrained (Fondahl, 1991) and these tools also have similar or the same limitations addressed above. Most importantly, these tools employ priority-based heuristics for resolving resource allocation (Christodoulou et al., 2010), but do not provide optimal resource planning and functionalities to analyze the optimum resource supply (Primavera, 2005; Harris, 2013; Siu et al., 2015) as will be discussed in Section 5.

There is also significant research performed on modeling of resource leveling and allocation, and resource optimization. Zahraie and Tavakolan (2009) proposed a stochastic multi-objective optimization model using non-dominated sorting genetic algorithm and discrete fuzzy sets, and Jun and El-Rayes (2011) also proposed a multi-objective optimization model using a genetic algorithm module to minimize undesirable resource fluctuations and maximize resource utilization efficiency. Koulinas and Anagnostopoulos (2012) proposed a resource allocation and leveling approach using a hyperheuristic algorithm. Bettermir and