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# Work breakdown structure (WBS) development for underground construction

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ABSTRACT

A work breakdown structure (WBS) can prove to be pivotal to successful project management planning. There are few published studies about the methodologies or tools to develop the appropriate WBS for a project, and those that are available are limited to the specific areas of construction such as apartment-building construction and boiler manufacturing. This research has an emphasis on developing a methodology with higher generalizability, which has the capability to be customized to complex underground projects. To address this issue, a new methodology that employs hierarchical neural networks to develop the WBS of complex underground projects is presented. This methodology has been applied to several tunnel case studies and it has been shown that for a real project, the model is able to generate the WBS and its activities that are comparable to those generated by a project planner. Consequently, it is concluded that these modeling methods have the capacity to significantly improve the WBSs for complex underground projects and improve key project tasks, such as workload planning, cost estimating and scheduling.



## 1. Introduction

A comprehensive efficient work breakdown structure (WBS) can prove pivotal within project management planning processes by partitioning projects into stages, deliverables and work packages. Consequently, it can positively impact other project management processes, such as activity definition, project schedule, risk analysis and response, control tools or project organization [1].

The planning of underground work and WBSs is different from other civil construction, when one considers the complexity, uncertainty and large number of activities involved [2]. An experienced complex underground project manager knows that despite detailed planning and execution, there is always the possibility of errors, mishaps and unexpected outcomes on the horizon. Developing the work breakdown structure of a complex underground project in a systematic, thorough, and methodological manner will decrease the potential for unwanted possibilities while providing a baseline for planning, estimating, scheduling and effective project management.

Despite such significance and repercussions, there is a dearth of research concerning methodologies or tools for the development of appropriate work breakdown structures (WBSs) for a project. The available research is mostly limited to a given range of construction projects, and therefore, the generalizability of the research remains limited to specific conditions. However, more recent research utilizing case-based reasoning (CBR) methods offers valuable material while providing a model for the acquisition and reuse of specific planning knowledge.

FASTRAK-APT, which was developed by Lee et al. [3], offers an important case- and constraint-based project planning tool for apartment construction. FASTRAK-APT relies on the fact that a human expert project planner uses previous cases for planning a new project. Despite the evident use of CBR methods for planning, the applicability of the system is limited; in contrast, the proposed methodology is applicable to domains that have available data and structured knowledge, such as apartment construction.

Dzeng and Tommelein [4] proposed a case-based expert system, CasePlan, based on a product model that describes and reuses the existing boiler erection project in power plant construction for planning a new project. The researchers believe that CasePlan will prove viable for projects with distinct components; thus, it may not be applicable for complex underground projects, which have no distinct component. Ryu et al. [5] developed CONPLA-CBR, a case-based reasoning planning tool with greater applicability. However, its applicability has not been evaluated for complex underground projects. More recently, some researchers have emphasized the use of neural networks in the development of planning systems [6,7]. Hashemi and Emamizadeh [8] proposed a decision tool that employs a modular neural network to plan the WBS of a limited project domain. The author cited the vast amount of knowledge required in generating a work breakdown structure as the primary reason why the use of neural networks is a

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preferable alternative; however, the proposed methodology is applicable to small-scale projects. For large-scale complex underground projects, the number of possible work breakdown structures and activities can expand rapidly and a bigger size of neural network should be employed. Therefore, designing and training of the neural network will be more complex and time consuming. Sharifzadeh et al. [9] formulated an approach for WBS development in tunnel projects using neural networks. Large-scale tunnel projects were tested by their proposed model; however, their model had the similar disadvantage, and hence the accuracy of the predicted WBS was decreased by increasing the number of WBS elements.

There is not a good process to objectively determine the WBS of complex underground projects and correlate them with the projects nature. With this in mind, this paper is going to introduce a process which helps a planer to make a more informed choice of WBS components and structure regarding project attributes. The outcome of the process is a hierarchical neural network, which has been implemented to develop the WBS of complex underground projects. First, the main concepts, including the work breakdown structure of a complex underground project and its attributes, are described, followed by detailed description of the proposed methodology. Finally, the results of applying the proposed methodology to several case studies are discussed.

## 2. Complex underground project attributes

Underground construction necessitates firm commitments and obligation to comprehensive and complicated procedures. Underground construction demands high management expertise to address complex and challenging eventualities. Lack of understanding of a number of significant factors, such as the unique contingent features and ensuing interrelated complexities, can increase the difficulties of underground construction endeavors [2]. Thus, complex underground construction projects are characterized by a large number of variables that can unfold in various quantities and combinations, including participating parties and individuals, a sundry of work packages at play, requirements, drawings, plans and reports, in addition to budget items and the time plan. Factors that affect project management may be enumerated as follow [2,10]:

1. Underground structures are a necessity of modern life, and such necessities cannot be disregarded.
2. Consideration of the needs of the general public as the major stakeholders is critical to the success of such projects.
3. Urban underground projects are constructed in dense, complex, and restrictive environments.
4. Public policy, public relations and the effective use of media can positively impact the construction of tunnel projects.
5. Underground construction is capital intensive and reliant on a high injection of initial capital expenditures.
6. Underground projects take considerable time to conclude.
7. Underground construction is carried out under conditions of geological uncertainty.
8. Underground construction is risky.

It is important to understand the key attributes of an underground project before the creation of the project WBS. Project stakeholders, for example, affect some of the main characteristics of the WBS such as the level of details. In larger projects such as subway tunnels, politicians, owners, nearby resident and public might be the stakeholders. On the contrary, smaller projects such as a diversion tunnel might have only one or two stakeholders including the members of the parliament and environmental organizations. It should be noted that these attributes vary in different underground projects in different countries. Other factors have more or less similar effects on WBS development. However, the complexity arises from the variation of these attributes in different underground projects. Geological conditions might be highly variable for a certain project while it is almost constant in another project. The expectation of an underground project client might be too high so that weekly reporting is required, whereas a client of another project needs monthly reports. A few millimeters settlement during the construction of an urban tunnel might be the concern of the nearby residents and hold the project for months, while larger settlements are acceptable in other projects [11]. All of these attributes affect the main characteristics of the work breakdown structure and they should be well understood before the development of the WBS.

## 3. Work breakdown structure (WBS) of complex underground projects

Work breakdown structure (WBS) is the process of dividing a project's overall work to several more manageable hierarchy structured tasks. The level of details should represent the overall scope of the project while keeping the tasks manageable [1,12]. The WBS is typically designed through a top-down procedure. The upper levels of the WBS are decomposed into logical groupings of work, followed by the next level down and so on. Thus, the lowest-level component of WBS can be scheduled, and its cost can be estimated, monitored, and controlled. Fig. 1 illustrates the work breakdown structure of a metro tunnel project as an example.

There are many different methods that can be employed to create a WBS. While there is general agreement that the WBS is the fundamental managerial component upon which many project management processes are based, there is surprisingly little agreement on the best method for creating the WBS [1]. One of the main questions in this regard is how the optimal WBS can be identified from all possible structures. The Project Management Institute [13] stipulated that “a quality WBS is a WBS constructed in such a way that it satisfies all of the requirements for its use in a project”. When applying this quality principle, the optimal WBS in a complex underground project is a high-quality work breakdown structure, wherein specific content and the type of WBS elements appropriately address the full set of needs of the project. Examples of a quality WBS characteristic in a complex underground project are as follow:

- Contains specific types of WBS components necessary for a complex underground project.
- Provides “sufficient” detail for communicating the scope of a complex underground project.
- Achieves a “sufficient” level of decomposition for effective complex underground project management.

Therefore the best method for creating the WBS of complex underground projects is a method that could find the optimal work breakdown structure with all necessary components, sufficient details and sufficient level of decomposition. One might ask what the exact definition of “sufficient” is in this context. Considering the varying attributes of a complex underground project, the real answer is that it depends. The attributes of a complex underground project entail the use of project-specific WBS characteristics. A specific WBS may prove highly appropriate for one project while failing completely for another. In fact, considering the variability and complexities of underground project management, it is not surprising that specific standards for WBS characteristics of complex underground projects are difficult to find.

## 4. Methodology

The overall process of the proposed methodology is presented in Fig. 2 under the headings ‘State Problem’, ‘System Design’, ‘Verification’ and ‘Validation’. The ‘State Problem’, ‘System Design’ and ‘Verification’ steps are presented in the following sections, while the ‘Validation’ step and results are discussed in Section 5.