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Risk modelling with Bayesian Networks - case study: construction of tunnel under the Dead Vistula River in Gdansk

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Abstract

The process of decision-making in public procurement of construction projects during the preparation and implementation phases ought to be supported by risk identification, assessment, and management. In risk assessment one has to take into account factors that lead to risk events (background info), as well as the information about the risk symptoms (monitoring info). Typically once the risks have been assessed a decision-maker has to consider risk-management activities that minimise the risk events (mitigating factors). Finally, the decision-maker has to select best response decision(s), i.e., one that would either maximise the benefits or minimise the losses. This selection is best performed in the framework of the utility theory. Thus, a good diagnostic-decision support model (D-DSM) has to integrate the following elements: background info, risk events, monitoring info, mitigation activities, response decisions, and associated with risk events and decisions utilities. Our purpose is to demonstrate how Bayesian Belief Networks (BBNs) can be used as D-DSM to assess and manage risks, and finally select best response decisions, during the implementation phase of a large construction project.

The authors use the example of a road tunnel under the Dead Vistula River in Gdansk (Poland). The D-DSM combines expert knowledge about the relationships among model components with the monitoring information. The model is able to use evidence from various sources in a mathematically rigorous manner. We demonstrate how the model may be used to estimate: the value of monitoring information (from the utility and diagnosis uncertainty perspectives) and the benefits of mitigation activities.

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Keywords: Bayesian network; construction management; monitoring; risk assessment; value of information.

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1. Introduction

To large extent, the success of a construction project depends on effective risk management, which in turn is concerned with correct evaluation of the probability of adverse events, particularly when new observations/evidence becomes available. These issues are not typically considered in the planning phase, which results in a lack of consistency between the design assumptions and the construction phase [1].

The purpose of the article is to demonstrate the possibility of using the Bayesian Belief Networks (BBNs) in the diagnostic-decision support model (D-DSM), In particular we are concerned with risk assessment and management for large construction projects. As an example we use a unique high-cost project with complex technology, namely the construction of a road tunnel under the Dead Vistula River in Gdansk. The application of the BBNs to this case helps us in assessing and managing the risks in the environment of uncertainty. This is achieved by a combination of monitoring data and expert knowledge [2,3]. The latter is used to determine the connections among the system's elements, whose strength is expressed by relevant conditional probabilities. Project planning that takes into account the risks of work disruption is a very important component of the investment process, as it reduces the probability of delaying each step of the construction, and thus also contributes to the reduction of unexpected extra costs, especially those related to the penalties for delays [4].

1.1. Data for BBN construction

For the analysis of risk and the estimation of the its value during the construction of the tunnel under the Dead Vistula River in Gdansk we build a probabilistic model based on the Bayesian Belief Network methodology [5,6]. For computer simulations we used the Netica software (Norsys - Netica Application - Norsys Software Corp) [7]. First, the analysis of project documentation was conducted and its results were combined with the information provided by the customer - Gdańskie Inwestycje Komunalna Sp. z o.o., To determine the network parameters (conditional probability tables and utilities) we used the expert brainstorming approach. After the initial network was created we verified its behaviour by performing numerous simulations and comparing the results to the experts' expectations. This seems to be a common approach for developing AI tools.

The risk model development for the tunnel under the Dead Vistula River in Gdansk began from the division of risks into four basic groups covering: the general risks, the risks resulting from the contractor's activities, the technical risks, and the executive risks [8,9]. In this paper, special attention is given to the high degree of risk arising from the technology and the work performance, due to the long duration of the investment and its unique character. In this group we identified the risk of damage to Tunnel Boring Machine, the risk of collisions of the construction work with existing underground networks, as well as the risk of damage to the existing adjacent facilities. Experts recognised that the analysis of all potential sources (factors) of risk is not feasible, and, in addition, such high resolution may distort the actual picture of the most important issues. In this example, we analysed only the factors that are most important from the customer's point. These factors constitute a sample set chosen for the examined risk behaviour.

2. Description of the decision problem

The purpose of the decision model presented on Figure 1 is to answer the question: whether to continue tunnel drilling activities considering updated (based on monitoring evidence) probabilities of selected risk events.

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