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A decision support framework for estimating project duration under the impact of weather

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A R T I C L E I N F O

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A B S T R A C T

This paper proposes a decision support (DS) framework that incorporates weather-related factors for the purpose of estimating the duration of projects. Inclement weather can have a serious effect on construction projects, particularly with regard to duration and costs. The weather has an impact on human resource productivity, supplier effectiveness and material damage which can, in turn, affect the duration of a construction project. The proposed five-module framework integrates weather variables, project performance variables and duration of project activities. This framework uses expert knowledge about the importance of weather variables, pairwise comparisons of weather variables with respect to different performance criteria, and similarly, pairwise comparisons of performance variables with respect to project activities. A model based on this framework, using multivariate statistical techniques and an analytical network process (ANP), is developed to estimate the duration of project activities, taking into account the impact of weather. The proposed model is illustrated with data from a construction project from Iran. Validation of the model is provided by comparing the actual duration of an activity with the estimated duration, using the proposed framework.

1. Introduction

Construction projects are commonly affected by multiple risk factors. According to Ghosh [21], risks can jeopardise the successful completion of a project by causing cost and time overruns. Risks in construction projects are divided into two main categories. These are defined as project risks (which are internal) and external risks [6,57]. Project risks relate to managerial factors, design documentation, human factors, delivery and logistics, and contractual elements [57]. External risks consist of legal, political [39,54], economic, social, natural [7,43,54,55] and technical risks. According to Sweis [58], the top three most important factors that cause time overrun in public construction projects are government delay (around 32%), inclement weather (23%), and design changes (18%). Moreover, severe weather can cause financial risks for construction projects [7].

Inclement weather has a direct effect on the health and safety of site labourers and can affect human resource productivity, supplier effectiveness and material damage [14,29,37,43]. Human resource productivity and the efficiency of construction activities are directly related [43]. According to Wiguna, Scott, and Khosrowshahi [62], inclement weather such as heavy rain affects sandy rivers and results in the sand mixing with mud. It also decreases the quality of the sand, causing a shortage in local market stock which leads to construction delays. While considerable work has been done to find the risk factors that affect the time and cost of construction projects, research that enables us to create or design an automated system to forecast and visualize the impact of weather risk on construction sites is scant. Hence, developing a decision support system for construction projects to estimate the duration of each activity (with respect to weather risk) is vital for project scheduling.

Moselhi et al. [43] have developed an automated decision support system (WEATHER) to predict the combined effects of reduced labour productivity and work-stoppage (caused by adverse weather conditions) on construction sites. However, even though WEATHER can provide an estimate of construction productivity as well as the duration

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of construction activities and weather patterns that facilitate the application of risk analysis in planning, it fails to consider the relationship between the effect of weather on construction resources and construction activities [43].

The objective of this study is to develop a framework to estimate project duration, taking into account the effect of weather on project performance. The proposed framework in this paper uses three databases or information sources: [a] a database of weather-related variables, [b] a knowledge base available to project managers (based on the interrelationship and relative importance of project activities) and [c] a historical project performance database. This framework integrates various multivariate statistical tools and multicriteria decision-making approaches to achieve its objective.

The rest of the paper is organised as follows: Section 2 reviews the literature on construction project performance monitoring tools and the impact of weather on project delays and costs. Section 3 briefly outlines the multiple methods used in this study. Section 4 presents the proposed conceptual framework. A model implementing this framework is illustrated with data from a real case in Section 5. This section also provides a statistical comparison of the actual and predicted duration of activities, thereby validating the model. Finally, the concluding section summarises the results and discusses future research directions.

2. Literature review

According to several previous studies, the possible causes of construction project delays vary from the faults and weaknesses of contractors, owners/clients, consultants and designers (internal causes), to environmental or governmental problems (external causes) [1,25,26,36,45].

Some of the main factors that cause cost and time overruns can be listed as follows: financial factors, lack of experience of the various parties, lack of qualified project managers, incomplete design at the time of tender, changes, lack of cost planning/monitoring during pre- and post-contract stages, poor condition of the site, adjustment of prime cost and provisional sums [26,34,35]. There are a number of other factors which can cause delay in construction projects, such as interruptions, lack of resources caused by contractors during the drawing phase, financial difficulties and changes to orders [38,46]. According to Kumar and Reddy [59], reliable forecasting of the duration of activities is one of the major issues faced by construction engineers. This relates to the factors that affect project duration, such as the uncertainty of events in the project environment such as weather, and productivity levels [59].

However, given the limited resources to examine all possible influencing factors in a single study on the one hand, and the impact of weather factors as the most influential factor on the other [5,6,19,54], in this study we focus solely on the impact of weather on the duration of construction projects.

In many construction activities, the weather is responsible for adverse effects such as stoppage, productivity loss, cost overrun and delay [5,6,19,54]. Among various weather conditions, rainfall and hot and cold weather are regarded as the major factors that affect building construction [31].

Many construction activities are highly sensitive to rainfall as this can reduce productivity (during the rainfall) and affect construction activities for several days afterward. Extremes of hot and dry weather can also affect human productivity (for example, due to the significance of thermal comfort) [37], and the time needed to complete other aspects of construction activities which are sensitive to weather (weather sensitive activities) such as the delivery of materials such as masonry mortar, paint, seals and sealant, and equipment [31]. According to the literature, different weather factors can affect cost and productivity, and cause delay in construction projects [33,56]. El-Rayes and Moselhi [20] confirm that rainfall can cause a complete stoppage in highway construction. Koehn and Brown's [37] investigation suggests a clear relationship between overall construction performance and weather-related factors such as temperature and humidity. For example, labour-dependent activities are generally affected by temperature and humidity, whereas crane operations are sensitive to wind speed [22,37]. According to Shahin et al. [56], inclement weather such as cold spells can have an impact on tunnelling projects and high-speed winds of more than 50 km/h, or low temperatures (e.g. below zero Celsius) can cause stoppage in building projects [56]. According to Haseeb et al. [25], a delay in a construction project is defined as exceeding the completion time with respect to the contractually agreed time [25].

Hence, weather can play an important role in estimating the duration of construction projects (which is an important factor in the preparation of a construction plan) as well as in the application of formal project scheduling methods such as the critical path method (CPM) or the programme evaluation research task (PERT) [42]. Uncertainties in relation to weather factors, design, labour efficiency, equipment, site condition and so forth may directly or indirectly affect construction scheduling and planning during project implementation [32]. Estimating project duration at the project planning and scheduling stage is somehow subjective and depends on engineering judgment [28]. CPM and bar charts are the most popular techniques for project scheduling; however, these techniques cannot handle uncertainty. Building on CPM and in order to handle the uncertainty (by taking risk factors into consideration), several techniques have been developed as follows: PERT [18], the probabilistic network evaluation technique (PNET) [4], and critical chain scheduling (CCS) [41]. Although these techniques consider uncertainties, they ignore the correlational impact between activities and risk factors [27,36,45,61]. They assume that there is no dependency upon the relationship between activities and risk factors [32].

Thus, there is a need for a more comprehensive decision support (DS) framework to take into consideration the correlations between activities and risk factors, in order to be able to estimate the duration of construction activities. The rest of this paper is devoted to developing such a framework with an illustration of a model based on that framework, and discussion.

3. Research methodology

This research uses multiple methodologies to integrate weather-related variables in the process of estimating the duration of activities affected by weather. For this purpose, multivariate data analysis methods such as principal component analysis, time series model building approaches, multi-criteria decision-making tools, non-linear multiple regression and qualitative and quantitative data collection methods are used and integrated into a framework. To validate the model developed from the framework, a real-life case is used. Validation is done by statistically analysing the difference between the duration predicted by the model with that of an actual case. Weather-related data that is collected from official meteorological sources from the region where the project is undertaken are used. Expert opinions on the importance of weather variables on the duration of project activities and performance are essential, so methods to elicit this information become important. Also, the relative weighting of the different factors and their interaction is found using multi-criteria decision-making tools, together with the input from experts. In addition, a