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Non-parametric weather generator for modelling construction operations: Comparison with the parametric approach and evaluation of construction-based impacts

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ABSTRACT

Weather generators are frequently used to provide a realistic environment to model weather-sensitive construction operations. Although a parametric weather generation approach is commonly used to construct such generators, this approach is associated with drawbacks such as the assumption that weather variables are normally distributed. In this paper, a simplified weather generation approach, based on the bootstrap technique, is proposed. An experiment comparing both approaches is conducted. A three-stage model evaluation has been applied to outputs from both generators. The evaluation includes: (1) an evaluation of both generators' assumptions, (2) a comparison of both generators' outputs with historical records, and (3) an evaluation of imperfection effects associated with the generators' outputs when applied on weather-sensitive construction models. Results indicate that although both generators are reliable for generating daily synthetic weather series and in modelling construction operations, non-parametric weather generators demonstrate a better performance when modelling time-scale flexibility (hourly/daily) in construction operations.

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1. Introduction

The construction industry is subject to a wide range of uncontrollable external factors that cause uncertainty in the planning, scheduling, and controlling phases of a project. Among these factors are changing weather conditions, which are environmental factors that significantly influence the efficiency of construction operations. The effect of weather conditions on construction projects is variable and is based on numerous factors, including types of construction, location, and season. Ahuja and Nandakumar [1] have stated that the reliability of project duration forecasting depends on the accuracy of network logic, individual activity duration estimates, and various uncertainty variables in the project environment, including weather. Losses in man-hours can also result from changes in weather conditions, with the impacts of weather on labour cost being classified into five groups: (1) bad weather time (describes the scenario where workers are paid, but no work progress is made), (2) reduced productivity (describes the scenario where worker output is reduced and additional paid man-hours are required), (3) repetition of work resulting from damage caused by weather variables such as wind, rain, or ice, (4) stood-off time (describes the scenario where workers are dismissed, absent, or reported late due to bad weather), and (5) a reduced working schedule due to bad weather [2].

Randolph et al. [3] found that 30% of loss in steel operation productivity is due to cold winter temperatures. Furthermore, Kohen and Brown [4] indicated that three quarters of worker compensation claims during the cold season are due to frostbite related injuries. To maintain a healthy working environment, the American Conference of Governmental Industrial Hygienists (ACGIH) [5] developed a warm-up schedule for construction trades in cold regions. Productivity is most affected by changes in weather conditions when construction activity is entirely dependent on labour. For example, high wind speeds dramatically exacerbate drops in temperature, making it impossible to sustain a constant labour production rate.

In earthmoving operations required for highway construction, weather is a critical factor that must be considered in productivity estimates. Material excavation and hauling activities are sensitive to rainfall and in some instances work may be either stopped or suspended as a result of unworkable soil conditions [6]. Experts in highway construction have indicated that the impact of rainfall is dependent on rainfall amount and timing, as well as on drying conditions. They also reported that an average of 1.5 days of earthmoving productivity is lost when rainfall intensity is between 13 and 25 mm [6].

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Previous studies investigated the effects of weather variables on construction activities. Ahuja and Nandakumar [1] and Kavanaga [7] considered the effect of weather as a percentage in their construction modelling and measured how frequently weather resulted in reduced activity. Moselhi et al. [8] quantified the impact of weather conditions on daily construction activity. El-Rayes and Moselhi [6] presented a decision support system for quantifying the impact of rainfall on the productivity and duration of highway construction operations. Wales and AbouRizk [9] and Shahin et al. [10] developed a stochastic weather generator that produces weather variables for use in construction simulation models. Apipattanavis et al. [11] proposed a framework for quantifying and predicting weather-related highway construction delays, which included a weather generator to provide a probabilistic forecast of weather threshold values. Although methodologically different, these investigations followed a similar pattern to build the required models and quantify their impacts on real projects by: (1) studying construction processes, (2) understanding the weather impact on those processes, (3) determining the weather variables that affect the studied process; (4) searching for source(s) of weather data, (5) selecting a modelling technique, (6) generating weather variables (the generation of weather variables is normally performed by developing a weather generator tool) and, finally, (7) applying the model to a case study project.

Fatichi et al. [12] defined weather generators as numerical tools capable of generating a time-series of climatic variables with statistical properties similar to conditions in the observed climate. These generators are used to generate synthetic weather series to help study weather-dependent processes. Depending on the process being modelled, weather generators differ in terms of time steps, single or multiple locations, and number of variables (e.g., temperature, precipitation, and wind speed).

A universal weather generator framework was proposed by Shahin [13] to be used in construction engineering and management research. The framework illustrated the use of the parametric stochastic weather generation approach to generate synthetic weather series with multiple variables. It used a first-order Markov chain model to generate precipitation, a multivariate generation model to generate temperature and relative humidity, and a probability distribution model to generate wind speed. This approach is associated with drawbacks including the selection of the order of the Markov chain model. Although the first-order Markov chain model is commonly applied to generate precipitation, this selection has been unjustified [14]. Chin [14] analysed 25-year records of precipitation from 100 stations in the United States and concluded that the first-order Markov chain model is adequate in resampling the wet and dry spells in the summer season. However, during the winter season, a higher-order Markov chain model was better than the first-order model at resampling the wet and dry spells. Chin also concluded that the geographical location of the studied area affects the selection order of the Markov chain model. Another drawback associated with the generation of precipitation is the generation amount. The parametric approach samples the amount of precipitation from a probability distribution function. The main challenge associated with this model is its ability to reflect the features found in precipitation data including bimodality, skewness, and long tail [15]. In addition, the parametric approach assumes weather data to be normally distributed, so that the multivariate generation model can be used to generate temperature and relative humidity variables. However, weather data from different locations may exert different distribution behaviour. Doubrovsky [16] constructed a stochastic weather generator called Met&Roll using the classical approach presented by Richardson [17] and conducted validation by comparing the generated monthly means with observed means from historical weather records. He concluded that weather variables such as solar radiation, maximum temperature, and minimum temperature did not follow a normal distribution. Another drawback associated with the parametric approach used in the universal weather generator framework is created by the gap between the large time scale (on a daily basis) of the generated weather variables and the time scale required by the application at which the weather generator is used. Most construction operations consider the effect of changes in weather conditions on a daily basis. However, some operations require hourly weather monitoring. Among these is earthmoving in mining industry, which often takes place in cold regions, and can be affected by weather conditions. The weather monitoring requirement adds complexity to the generation of hourly weather variables. Although parametric approaches are expected to improve generated weather series, they still have several inadequacies: (1) the choice of model is subjective (e.g., modelling weather variables by fitting them into their distribution independently or using multivariate models) and is rarely tested on a site-by-site basis [18], (2) the distribution of weather variables used at one site may not be appropriate for all sites [18], and (3) the multivariate models require data to be normally distributed. In cases in which they are not normally distributed, a transformation to normality is required. This is a difficult task that may negatively affect model performance [19].

Detailed records of historical weather data for almost all locations in the world are publically available. Using such high quality records, it is possible to directly sample realistic weather parameters for different times and locations. Realistic extreme cases can also be generated from these records. This paper illustrates a simplified, non-parametric weather generation approach that uses the classical bootstrapping technique to generate a synthetic weather series.

Unlike the parametric approach, there is not a requirement to assume a theoretical probability distribution function for weather variables in the non-parametric approach. The non-parametric approach preserves serial dependence between weather variables by using a block-resampling scheme that considers a block of observations as a single observation and generates daily and hourly weather variables. However, the generated weather series in the non-parametric approach is limited by historical records, as simulated samples are selected from available (past) weather data. Therefore, an experiment on both parametric and non-parametric approaches was conducted to highlight differences between both approaches from two perspectives: the generated weather series and their performance when applied on weather-sensitive construction models.

In this experiment, a weather generator framework developed by Shahin et al. [20] to simulate construction operations is used to compare the proposed non-parametric approach to the parametric approach for generating weather variables. The framework applies the parametric approach to generate weather variables. The parametric approach used by Shahin et al. [20] shares the same drawbacks discussed previously. In addition to the drawbacks, wind speed is modelled independently with no correlation to other weather variables and the generated weather data is limited to a daily scale.

The paper is organized as follows: Section 2 presents a detailed description of the experiment applied to both parametric and non-parametric weather generators. Section 3 describes how both generators are developed. Section 4 illustrates a comprehensive weather generation evaluation process, which tests the weather generators' performances from the perspectives of the assumptions applied and outputs generated. The process also assesses the generators' performance when applied on construction simulation models. Section 5 presents the conclusions of the study.

2. Experimenting with parametric and non-parametric approaches

For this study, a non-parametric weather generator was developed and its performance compared to a previous weather generator using historical records as a baseline. Fig.1 shows a summary of the study methodology, which begins by selecting the location of study. This step was performed to determine what weather variables may directly affect construction operation performance at that location. For the purpose of this investigation, Fort McMurray, Alberta was selected as the location of study. However, a different location may be chosen, provided that weather records are available. Fort McMurray is located in the

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