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Fuzzy duration forecast model for wind turbine construction project subject to the impact of wind uncertainty

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ABSTRACT

Wind energy is one of the most promising renewable energy and wind farm is globally constructed for sustainable development. However, wind could produce adverse effects on some wind-sensitive tasks of wind turbine construction projects. Due to limited understanding of how wind may influence productivity in wind turbine construction project, this research presents a fuzzy duration forecast model for wind turbine construction project subject to the impact of wind uncertainty. Through the use of Beaufort scale, professional expertise, and fuzzy membership functions, the productivity loss (PL) subject to various Beaufort scale of wind can be analyzed. With historical wind speed data incorporated, the duration can be simulated and forecasted by the model. Besides, the practicality of the model is demonstrated by an actual wind turbine construction project. The findings from this research are very useful in allocating schedule risk for wind turbine construction projects where wind uncertainty arises.

1. Introduction

Due to the rapid depletion of natural resource, wind energy has been obtaining a considerable attention as an alternative to conventional fossil, coal, or nuclear sources of energy in recent decades. Because of its characteristics of cleanness, inexhaustibility, low pollution and low cost, wind energy becomes one of the most promising renewable energy sources worldwide. Therefore, many countries are increasingly interested in establishing wind farms with multi-megawatt sized wind turbines for sustainable green energy developments [1–4]. Ritter et al. [5] noted that the global cumulative installed capacity of wind energy increased from 6 GW in 1996 to 318 GW in 2013 and is expected to reach 596 GW in 2018. Thus, it is foreseeable that a large number of wind turbine construction projects will be carried out worldwide in the near future.

Wind turbine construction projects are normally carried out in an outdoor environment, particularly onshore or offshore with plentiful of wind energy. Weather can affect construction tasks in various ways [6,7]. Hence, the construction tasks of wind farm projects are inevitably affected by the presence of wind uncertainty. For example, lifting tasks of wind turbine construction projects are very sensitive to the adverse impact of wind uncertainty, which often leads to significant loss of productivity and, even worse, complete suspension of construction tasks as a result of severe impact of strong wind. Accordingly, wind is a significant weather risk for productivity loss and schedule delay in wind turbine construction projects.

To ensure being completed within expected date, most wind turbine construction projects are now awarded on a calendar-day basis in Taiwan, in which the contract period has been specified without considering the wind uncertainties in each calendar day. If the wind uncertainties are beyond expectation, risks of schedule delay may occur. As results, the contractors will take more schedule risks than ever before. Project management is to keep the project on the track of the developed schedule plan by minimizing the adverse risk. Also, it is about dynamically adjusting the plan suitable for the reality [8]. Hence, how to prepare a risk-minimized schedule plan is essential for the contractor to prevent the adverse impact of wind uncertainties. Unfortunately, conventional scheduling techniques (e.g., critical path method) are not able to catch the impact of wind uncertainties. In practice, with project information available, the impact of wind uncertainties is usually estimated by a rule of thumb based on engineers' past experiences and experts' subjective judgements and is roughly adjusted by adding an estimated amount of time. However, different experiences and judgements from various professionals will result in different adjustments. Also, inappropriately adjustment could not keep the project on the track of the stipulated schedule plan, which results in raising serious events of disputes or penalty between the contractor and the owner, also prolonging inconvenience to the public [9]. Simulation is an effective approach to handle the uncertainties involved in various aspects of construction management, such as scheduling and productivity estimation [10]. Therefore, scientifically simulating various scenarios based

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on historical wind speed data in plan/design phase would more accurately evaluate the impact of wind uncertainties to minimize the duration risks of wind turbine construction project.

Forecasting the future durations for wind-sensitive tasks in advance is useful for schedule planning in order to avoid the adverse impact of wind uncertainties, which often lead to productivity loss. Accordingly, accurate predictions of future duration for wind-sensitive tasks based on productivity loss are essential to develop an optimal schedule strategy. However, the estimations of productivity loss are usually gathered from professionals' subjective assessments using linguistic descriptions such as "the productivity loss of lifting task is about 40% in fresh breeze condition" which are innately imprecise or fuzzy. On the other hand, wind speed data affecting productivity are numerical. Accordingly, information with regard to the impact of wind uncertainties on productivity loss is a mixture of fuzzy data and crisp data. In order to assess the impact of wind uncertainties which are linguistic, vagueness, and subjective in nature, fuzzy sets-based technique can be utilized [11]. Ayyub and Haldar [12] applied fuzzy set and systems theory to translate linguistic variables into mathematical measures to solve weather and labor-skill uncertainty problems in construction project scheduling process. Smith and Hancher [13] utilized basic fuzzy-set operations to evaluate the schedule impact of precipitation combined with rainfall prediction by utilizing a Markov process so as that contractor can evaluate time-extension requests properly. Lorterapong and Moselhi [14] presented a fuzzy network scheduling method (FNET) based on traditional fuzzy sets operations to model the uncertainties which result from expert's perception of the project when estimating activity durations in network analysis. Guo [15] also developed a computer-aided system with fuzzy-set techniques, historical precipitation records, and expert experiences incorporated to forecast project duration subjected to the impact of rain. Pan [16] presented a fuzzy reasoning knowledge-based scheduling system (FRESS) to assess productivity and duration of highway construction activities subject to impact of rain. Taiwan is an oceanic island on the western edge of the Pacific Ocean. Both wind and precipitation are significant weather risks for schedule control in construction. The impacts of precipitation on construction schedule have been studied and analyzed [13,15,17,18]. Moreover, construction labor productivity affected by temperature and relative humidity has been researched [19,20]. However, the impact of wind uncertainties on productivity loss and scheduling of wind turbine construction project has been still lacking.

With the assistance of professional expertise, the incorporation of fuzzy-set approach, as well as the utilization of historical wind speed data, this research presents a fuzzy duration forecast model for wind turbine construction project subject to the impact of wind uncertainties. An appropriate duration for each wind-sensitive task based on no-wind condition can be assigned based on a rule of thumb; afterwards, the forecasted duration subject to the impact of wind uncertainties can be derived by the proposed model. An application example using this model to forecast the duration of wind-sensitive tasks is presented using actual wind speed data from Taiwan. This model is easier to follow and simpler to apply. By employing this approach, the duration can be more accurately predicted even though without much relevant working experience provided.

2. Analysis of measured wind data

Since no wind events can be accurately forecasted, instead of experiences and judgements, historical wind speed data become mandatory parameters in developing the fuzzy duration forecast model for wind turbine construction project subject to the impact of wind uncertainty. Usually, these data can be obtained from the Weather Authority. The Central Weather Bureau (CWB) in Taiwan has set up many meteorological stations across Taiwan since 1961. Consequently, over decades of long-term measured data sources of hourly mean wind speed can provide environmental information for the application of the proposed fuzzy duration forecast model.

Accurate measurement of wind speed is necessary. Usually, wind speed data are measured by an anemometer in each meteorological station. These anemometer measurements are commonly taken at different fixed heights above the ground level, which might be different from the standard height of 10 m above the ground level and the hub height of a wind turbine. In wind turbine construction projects, the arm of a crane usually extends higher than the hub height of a wind turbine in order to carry out the lifting tasks. After completion of construction, the success of the subsequent testing and commissioning jobs also relies on the wind speed at the hub height of a wind turbine. Therefore, the wind speed at hub level should be determined. Physically, wind speed varies considerably with height within the first few tens of meters in the atmosphere. Also, wind speed fluctuates significantly with time. These make the data collection of wind speed at hub height a challenging job. To transfer the wind speed at anemometer height to the wind speed at hub height of the wind turbine, several models have been developed to describe this variation of wind speed. The power law model is widely applied in practice for height projection of wind profiles [21–25]. Hence, the power law model is herein used to calculate the wind speed at the hub level of wind turbine as shown in Eq. (1):

The Power Law Model:

$$\frac{V_1}{V_2} = \left(\frac{Z_1}{Z_2}\right)^{\alpha} \tag{1}$$

where

V_1 = wind speed at the hub height Z_1;
V_2 = wind speed at anemometer height Z_2; and.
α = the power-law exponent; (a general accepted value for open land is 1/7)

In reality, the general public does not recognize wind levels as expressed quantitatively by the exact amount of wind speed, such as 6.2 m/s, 6.5 m/s, or 8.8 m/s. Instead, people perceive wind levels as described linguistically, such as calm, light air, light breeze, gentle breeze, moderate breeze, fresh breeze, strong breeze, and near gale. For classifying various levels of wind with corresponding range of wind speed, the Beaufort wind force scale is the most widely used system in many countries, including Taiwan, as shown in Table 1. The Beaufort scale defines and classified thirteen levels of wind, i.e. calm, light air, light breeze, gentle breeze, moderate breeze, fresh breeze, strong breeze, near gale, gale, strong gale, storm, violent storm, and hurricane, as well as their corresponding range of wind speed, i.e. <0.3, 0.3–1.5, 1.6–3.3, 3.4–5.4, 5.5–7.9, 8.0–10.7, 10.8–13.8, 13.9–17.1, 17.2–20.7, 20.8–24.4, 24.5–28.4, 28.5–32.6 and >32.7 m/s [26]. The classification describes effects of various wind levels, from Beaufort scale zero - smoke rises vertically to Beaufort scale 12 - causing violence and destruction is based on observation of land or sea condition rather than accurate measurement. In Taiwan, Beaufort scale 8 through Beaufort scale 11 is referred to as mild typhoon and Beaufort scale 12 is referred to as hurricane. Since there will not be any wind turbine construction task carried out during typhoon and hurricane situation, Beaufort 0 (calm) to Beaufort 7 (near gale) is, hence, adopted as the scales of wind force in this research, including "Beaufort scale 0 – calm – less than 0.3 m/s of wind speed", "Beaufort scale 1 – light air – 0.3 through 1.5 m/s of wind speed", "Beaufort scale 2 – light breeze – 1.6 through 3.3 m/s of wind speed", "Beaufort scale 3 – gentle breeze – 3.4 through 5.4 m/s of wind speed", "Beaufort scale 4 – moderate breeze – 5.5 through 7.9 m/s of wind speed", "Beaufort scale 5 – fresh breeze – 8.0 through 10.7 m/s of wind speed", "Beaufort scale 6 – strong breeze – 10.8 through 13.8 m/s of wind speed", and "Beaufort scale 7 – near gale – 13.9 through 17.1 m/s of wind speed".