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A SIMULATION-BASED FRAMEWORK FOR QUANTIFYING THE COLD REGIONS WEATHER IMPACTS ON CONSTRUCTION SCHEDULES

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ABSTRACT

In cold regions, weather severity has a major impact on construction activities carried out in the open, leading to significant deviations from baseline schedules. Faced with weather uncertainty, setting up the project baseline schedule, against which performance will be measured, can be challenging. Construction planners often depend on their personal judgment and experience to account for the scheduling impact of cold weather. Due to variation in planners' experiences, the regions where their experience was acquired, and the time of year when the planned project is to be executed, the result can be widely differing plans between planners. This paper presents a structured simulation-based approach that attempts to account for the cold weather impacts on project schedule. This approach relies on generating weather sequences similar to the existing historical weather data for the project's geographical region. The impact on productivity and project schedule can then be modeled, leading to consistent schedules.

1 INTRODUCTION

Construction projects are generally subject to several factors leading to uncertainty in the planning stage. Planning for cold weather construction is characterized by a great deal of uncertainty in the estimation of activity durations and in determining the logic of performing the tasks based upon the weather conditions. A considerable portion of Canada's heavy construction takes place in cold weather. Cold weather can severely impact construction projects carried out in an open environment, leading to significant deviations from the scheduled finish dates. Planners often depend on personal judgment to estimate the potential impact of cold weather on a construction project. A more rigorous analysis is needed in order to provide more accurate project plans.

In this paper, a framework is proposed for simulating construction projects that take place in cold regions. The uncertainties caused by weather can significantly affect a project's schedule, resulting in significant variations as compared to the baseline schedule. The proposed framework represents an attempt to structure the way an engineer would approach the project and its structure of activities in order to develop an understanding that would enable the quantification of weather effects and account for their impact on the project baseline.

2 OVERVIEW OF THE FRAMEWORK

The framework is composed of a collection of components that help in understanding and simulating construction projects that are subject to the uncertain effects of weather. The framework also details the steps needed to model successfully the weather-sensitive activities. This model will allow the researcher to quantify the weather impact on the project schedule. Figure 1 shows the proposed cold weather simulation framework. The components of the framework will be handled in the following sections.

The goal of the proposed framework is to produce a library of simulation models that are representative of the various weather-sensitive construction processes requiring execution. The library is in fact a collection of work pieces, the seed for which is being planted in this research. In Figure 1, the construction process that is under review is referred to as construction process "X", and is representative of any construction process under consideration (e.g. tunneling, pipeline construction, or building construction). The following sections will be a description of the steps needed for the successful modeling of process "X." It should be noted that the goal of the library is simply the collection of the different construction processes' simulation models, which are themselves the aggregate of sequential steps that are proposed by the framework.

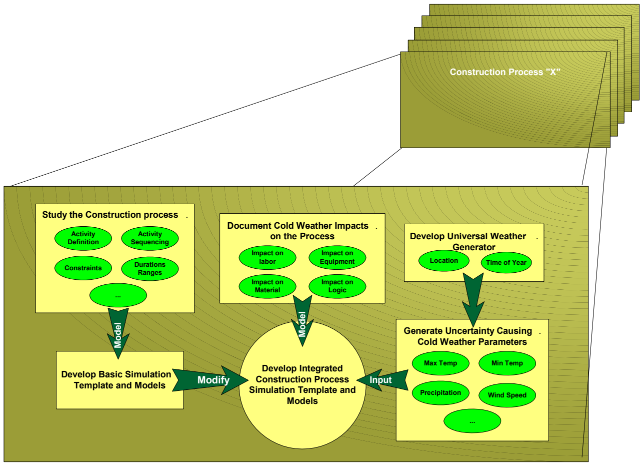

Figure 1: Proposed cold weather construction framework

3 COMPONENTS OF THE FRAMEWORK

The proposed cold weather construction framework is composed of a number of components that will be integrated together. This integration will facilitate the inclusion of the weather effects and will improve the evaluation of their impacts on the project schedule in the planning stage of the project.

The components of the framework help to develop a good understanding of the construction process under consideration, which entails studying the process at the activity level and documenting the impact of weather on the process and its activities. The weather-generating component, which is another integral part of the framework, is responsible for stochastically generating the uncertain weather parameters for the project.

3.1 Detailed Process Study

The first step of applying the framework to account for the impacts of cold weather on a particular construction process is to analyze the process in order to develop a better understanding of its details. At this stage, the impact of weather uncertainty on the construction process will be overlooked.

Site visits should be scheduled, and the process should be watched and documented by the engineer. This entails documenting many aspects of the process, including:

- The work breakdown structure of the process activities,
- The logic of performing the tasks and the activity sequencing,
- Any process constraints or dependence on external factors (e.g. material delivery) should be noted,
- The resource requirements of each activity of the process should be studied: the types or resources needed, the required level of resource, and the priorities of the different activities sharing the same resource should be determined, and
- Data about the average productivity rates for each activity should be collected. For example, in the case of labour productivity, the average level of labour productivity at the crew level could be measured using Equation (1).

$$\text{Average Labour Productivity} = \frac{man-hours\ \ used}{quantity\ \ produced} \qquad (1)$$

The average productivity value could be documented based on historical data, expert opinion, or standard estimating manuals. In commercial construction, it could be the estimated or budgeted productivity at completion, which is normally treated as a constant parameter (Thomas and Yiakoumis 1987). In many cases, the engineer might choose to study the effect of weather uncertainty on activity durations, in which case activity durations data should be collected.

3.2 Developing the Basic Process Simulation Model

After gathering all the required information about the process under consideration, the next step is to develop a basic simulation model for the process while disregarding the impact of cold weather.

At this stage, the engineer has the option to develop the simulation model for the process using discrete event simulation or using combined discrete-continuous event simulation. Both approaches will be sufficient for this step; however, it is important to note that developing a combined discrete-continuous event model will most likely require fewer modifications in order for the basic model to be adapted to include the weather impacts on the process. This adaptation will be handled in Section 3.5.

The combined discrete-continuous event simulation model details the construction process at the operation level, which requires detailed information and a better understanding of the construction process under consideration (Shi and Abourizk 1998). For that reason, the previous step, handled in Section 3.1, is crucial for the success of the final model. Also, developing the basic simulation model serves to promote a better understanding of the details of the process, which in turn facilitates the integration of the weather impacts in the final model.

The main target of this step is to make sure that the model is an acceptable abstraction of the construction process. For that reason, the basic simulation model should be validated and tested to ensure that it is capable of simulating in sufficient detail the construction process and is an acceptable abstraction of it.

3.3 Documenting the Impact of Weather on the Process

Weather can impact a construction process in various ways (Moselhi et al. 1997). In severe conditions, certain activities, and sometimes the whole project, can be halted. Bad weather conditions can slow down a construction process by lowering the productivity of the construction crews and equipment. Additional activities can also be added to the construction process to counteract the negative impact of the cold weather. An example is the excavation activities for pipeline construction in which the soil is frozen, thereby severely impacting the productivity of excavators. In such cases, an additional ripping activity is added to the process to counteract the impact of the frozen ground on the excavation activity productivity.

To facilitate the task of documenting the required information about a process, Figure 2 can be used to guide the procedure of documenting the impact of weather on a construction process. First, the process stoppage conditions should be investigated. These conditions affect the entire process; and when triggered, the conditions bring the entire process to a halt. An example of this is the need to stop all the activities of the tunneling projects whenever the ambient temperature is less than –40oC.

Benjamin and Greenwald (1973) suggest that approximately 50% of construction activities are affected by weather. The second step, therefore, in collecting data about the effect of cold weather on construction activities, is to go over the work breakdown structure (WBS) of the process activities and investigate which of the activities are sensitive to weather effects and which are not. The following is a summary of the data that must be documented for each weather-sensitive activity:

- Influencing weather parameters;
- Stopping conditions; and
- Model describing the relation between the weather-sensitive activity and the influencing weather parameters.

For the identified weather-sensitive activities, the influencing weather parameter should first be identified. For example, crane operations are sensitive to the wind speed, whereas labour-dependent activities are generally influenced by the effective temperature and relative humidity (Thomas and Yiakoumis 1987, Koehn and Brown 1985).

Following the identification of the weather-sensitive activities and their influencing weather parameters, the weather-sensitive activity stoppage conditions should be identified. These conditions will be based on the range of the influencing weather parameter within which the weather-sensitive construction activity is forced to halt. In the tunneling process, for example, the crane is supposed to stop working whenever the wind speed is more than 50 km/hr.

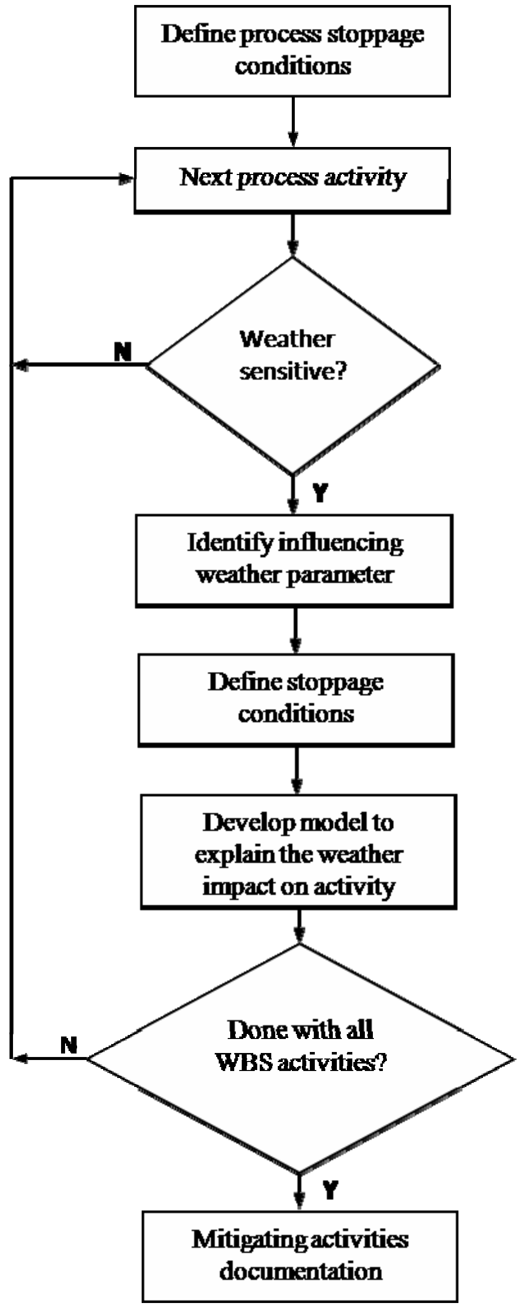

Figure 2: Impact on construction process documentation flow chart

Next, the extent of the influence of the weather parameters on the weather-sensitive activities should be investigated. This is generally achieved by assessing the impact on task duration. To carry out the calculations, a selection between either the impact directly on the task duration, or on the task productivity under varying weather conditions should be made. General guidelines for this selection are given in Section 3.5.

If task productivity is chosen, daily productivity factors (PF) can be used to assess the weather impact on the activity. The objective of this step is to quantify the effect of the weather parameters on the weather-sensitive activities' performances. This could be done using regression analysis (Thomas and Yiakoumis 1987, Koehn and Brown 1985). In previous cases, neural networks have been used (Wales and AbouRizk 1996). Another alternative is to use expert judgment and translate the experts' knowledge into a collection of if-then rules through which the effect of uncertain weather parameters on the sensitive activities could be identified.

If regression or neural networks are chosen for the analysis, site data collection or historical records, if available, will be needed. For example, if task productivity is chosen for the analysis, the daily productivity factors (PF) can be calculated using Equation (2). On the other hand, if task duration is chosen, the total task duration or the duration required to produce a certain number of units can be targeted for data collection. Please refer to Section 3.5 for further guidelines on this issue.

$$\text{Productivity Factor (PF)} = \frac{average \quad productivi\ ty}{actual \quad productivi\ ty} \qquad (2)$$

Productivity factors less than 1 mean that the actual productivity is worse than average. It should also be noted that Equation (2) is compatible with this convention for labour activities, where the average productivity values are measured using Equation (1). However, for other activities, in which the average productivity values measured, for example in units produced per unit time, increase with the improvement in productivity, the reciprocal of Equation (2) should be used to measure the PF.

Along with the productivity factors and task durations, the values of the influencing weather parameters (i.e. temperature, relative humidity, wind speed, etc.) should also be collected. After the data have been collected, a mathematical relation should be established between the influencing weather parameters and the productivity factors or task durations achieved in the field. This is established as the statistical or neural network model is developed.

Another aspect of the impact of weather on the construction process that needs to be investigated and documented involves those incidents in which certain activities, which were not present in the original process, are added to ease the impact on the process. These are called mitigating activities. They are normally triggered when a weather parameter reaches a certain level. For example, in the pipeline installation process, if the frost depth exceeds one foot, then the trenching productivity of backhoes is severely affected. In such cases, a ripping activity, which is not normally conducted in the typical construction process, can be added to ease the impact on productivity.

Several factors related to these mitigating activities should be identified, including their triggering condition, their role in the construction process, and their relation to the process logic. In addition, their productivity values should be documented for inclusion in the integrated simulation model.

3.4 Stochastic Weather Generation

PERT or Monte Carlo simulation can be used to quantify the impact of uncertainty variables on different construction processes; however, these techniques assume that the project tasks' durations are independent random variables. The methods are unable to establish the cause of uncertainty, making them unsuitable for modeling the impact of weather on construction processes (Wales and AbouRizk 1996).

To better model the impacts of weather on construction processes, the task should be broken down into two steps. The uncertainty variables should first be quantified through stochastic generation of the influencing weather parameters. Secondly, their impact on the activities' productivity or duration should be simulated.

In this research, a very important requirement of the framework is to build a good stochastic weather generator that can generate series of weather sequences of the most influential weather parameters affecting construction. The weather sequences must keep the historical serial correlation of the weather parameter values and keep the historical cross correlations between the different generated weather parameters. Statistical tests are recommended to verify the developed model and to confirm its conformance with these requirements.

Attention should be given to the weather variables that affect productivity and, in particular, those that could lead to activity or entire process stoppage. The following list of such weather variables were targeted for inclusion in a stochastic weather generator:

- Precipitation,
- Maximum and minimum temperatures,
- Average daily wind speed,
- Maximum and minimum relative humidity, and
- Frost penetration in the ground.

Although frost penetration is not a weather parameter by itself, it is closely related to temperature; it has a significant effect on many construction activities. It was therefore logical to include it in the stochastic weather generation model.

For the purposes of the developed framework, all the preceding weather parameters were successfully generated and statistically tested. Figure 3 shows an illustration of the generated max and min temperature for the city of Edmonton, which was generated for an entire year. Also the parameters experienced in the year 1967 are plotted. Pattern similarity between the two graphs can be seen.

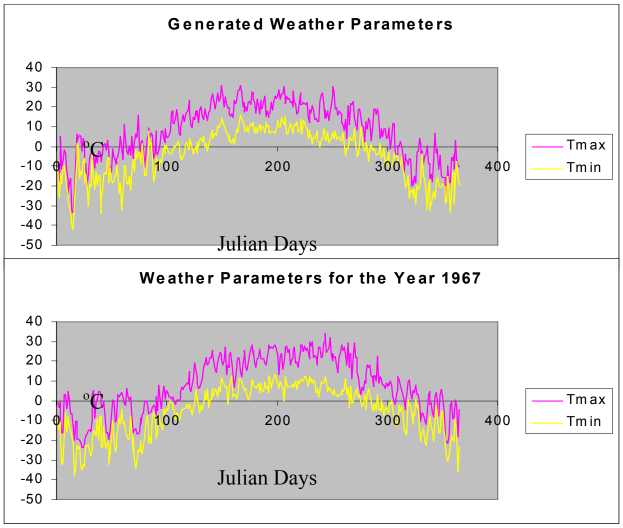

Figure 3: Generated vs 1967 temperatures

3.5 Developing the Integrated Process Simulation Model

The final step in modeling the impact of cold weather on a construction process is to integrate the process simulation model with the stochastic weather generator. To achieve this, the basic process simulation model should be extended to reflect its relation to the uncertain weather parameters. Furthermore, the logical clock of the simulation should be integrated with a calendar. Each day, both the logical time clock and the calendar advance one day. The weather for that day is then generated. Next, the progress of the weather-sensitive activities can be advanced using the PF model or the task duration model developed in Section 3.3. When using the PF model, predictions of the actual productivity for that day can be made using Equation (2). That way, the activity progress can be assessed based on the generated weather for that day. After updating all the process activities' progress, the logical time and calendar advance one day and the procedure repeats.

It is preferable that the engineer makes any decisions regarding the simulation model type (i.e. whether discrete or combined discrete-continuous simulation model) and the data to be collected (i.e. duration to accomplish a task or PF data) before developing the basic simulation model in order to minimize the amount of modifications in the integration stage. To help answer those questions, the flowchart in Figure 4 can be used. It should be noted that activities that are not weather-sensitive should not require any modification to extend the basic simulation model to the final integrated model. The engineer's prior choice for modeling those activities, whether discrete or combined discrete-continuous event simulation, should not require any further modifications at this stage.

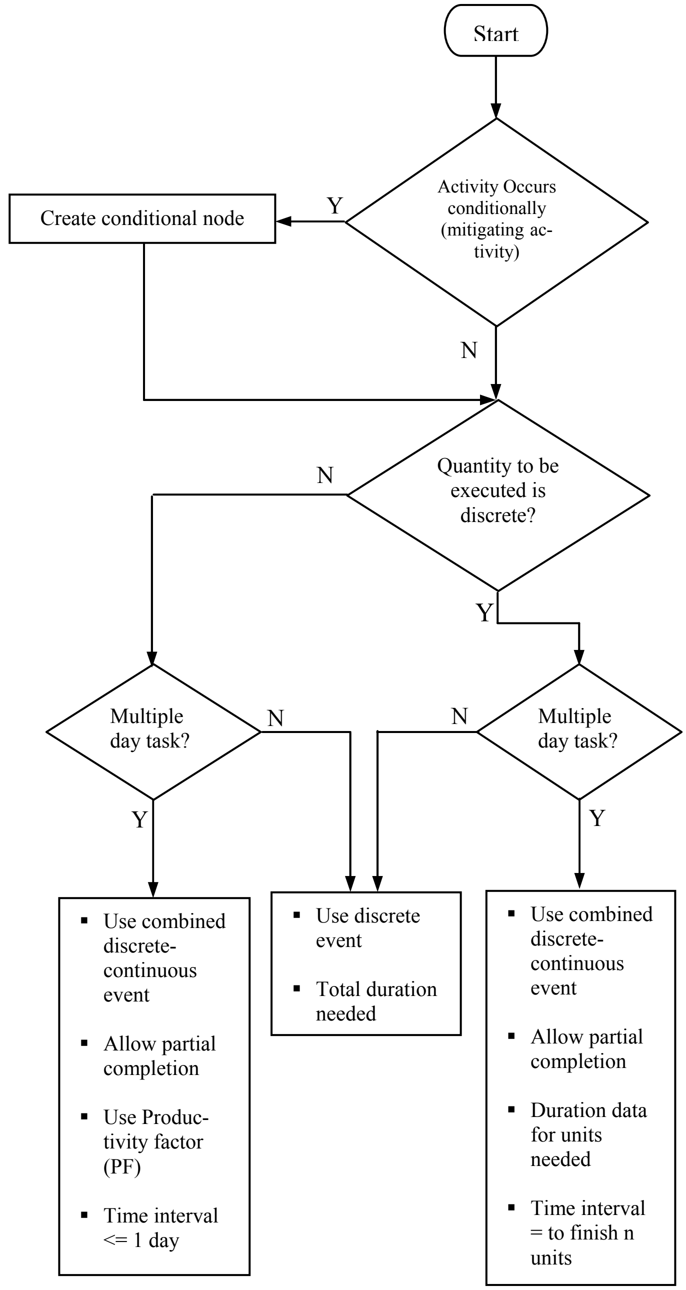

Figure 4: Flow chart to facilitate the integrated simulation model choices

To extend successfully the basic process simulation model, it is important to answer and decide a number of issues for each weather-sensitive activity in the process. Questions designed to prompt answers to each issue are illustrated in Figure 4. Those issues are listed below:

- Will the activity be modeled using discrete event or combined discrete-continuous event simulation?
- Will task progress be assessed using PF or task duration will be calculated directly?

- What is the time interval between data collections or task progress updates?

Referring to Figure 4, for each weather-sensitive activity in the process, the first question is whether this is a mitigating activity. If it is, then a conditional node should be created in the simulation model. The mitigating activity progress or duration will only be valid if a certain triggering condition regarding the influencing weather parameter is present; otherwise, the node should be treated as a dummy node.

The next question is whether the quantity to be executed is a continuous quantity (e.g. excavation or masonry) or discrete (e.g. pipe welds or crane lifts). In continuous quantities, assessing task progress using productivity factors is recommended. If the entire task is expected to be executed in multiple days then discrete-continuous event simulation in recommended to model the activity, the time interval between successive progress updates must be less than or equal to one day due to the weather parameters' daily updates. At the end of every update cycle, partial completion of the activity should be allowed.

For discrete quantity tasks, activity progress is assessed based on the number of discrete units completed and the duration needed to execute them. For multiple day tasks, using combined discrete-continuous event simulation is recommended in that case. The time interval between successive progress updates should be based on the time to finish n number of units, which will require data collection related to the duration required to execute the n discrete units. At the end of every update cycle, partial completion of the activity should be allowed.

In either case (discrete or continuous quantities), if the entire task is expected to be executed within a single day, then discrete event simulation modeling for this task is recommended. This will need data collection related to the total task duration, which might require developing a separate regression model.

CONCLUSION

This research presented the development and successful implementation of a framework for simulating construction projects that take place in cold regions.

The high level of uncertainty in cold regions' winter weather coupled with the variation of the project planners' experiences and the anticipation of the impact of cold weather on the construction projects were identified as factors contributing to the uncertainty experienced in cold regions construction planning. The need for a well-structured and consistent approach to account for cold weather impacts on a construction project was obvious. Due to its efficiency and flexibility in modeling construction processes, simulation was chosen as the main tool to host the proposed framework.

To ensure consistency, defined steps were given and the details involved in applying the framework were outlined, enabling construction planners to apply the framework in order to assess the impact of cold weather on a construction process.

A good stochastic weather generator that can successfully generate the effective weather parameters was identified as a required component of the framework. The needed weather parameters to be generated for the construction field were identified.

The current state of practice works by attempting to directly estimate the impacts on the activity durations. This research promoted another approach, which is more consistent and offers great flexibility to industry practitioners in accounting for the impacts of the different weather factors on the construction process by:

- Providing construction planners with a sound and structured way to account for the cold weather uncertainties in their planning.
- Helping construction planners to develop realistic schedules that take into consideration the location of the project, the time of the year in which the project is to be executed, and the impact of cold weather on the project they are planning for.

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