METHOD FOR CALCULATING SCHEDULE DELAY CONSIDERING WEATHER CONDITIONS

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As construction work is affected by weather events such as snow, cold temperature, humidity, and rainfall, conditions. Thus, to calculate acceptable delay duration, a reasonable method, suitable for practitioners, for predicting schedule delays caused by weather conditions is necessary. Therefore, in this study, we propose a method for calculating construction schedule delays where weather conditions are taken into consideration. This methodology combines weather information, the expected delay to particular types of construction as a result of altered weather conditions, and scheduling data, to determine the project duration and make it possible to reduce delays with the help of changes in commencement time of the project or modified scheduling. The objectives of the paper are twofold. The first objective is to provide a prediction of the potential delay as a result of weather conditions. The second objective is to help planners to make decisions making regarding the optimum construction approach to meet the project schedule given expected weather conditions.

Keywords: construction, delays, schedule, project management, weather.

INTRODUCTION

One of the significant risks in the delivery of a construction contract is the effect on delivery time of delays in critical activities. Some delays, such as those caused by weather conditions, are beyond the contractor's control, could not have been reasonably anticipated at the time of bidding for the contract. These delays make it difficult or impossible to meet the project completion date (Halpin 2005).

Delays are acts or events that extend the time necessary to finish activities under a contract (Stumpf 2000). They are a common problem encountered on construction sites and can be costly. Analyzing construction delays has therefore become an integral part of the project's construction life (Alkass *et al.* 1995).

Predicting project delays is valuable, particularly at the time of bidding for the contract. Once an issue has been recognized as a delay to an activity, the construction manager needs to establish the length of the delay and its effect on the project schedule. In many cases, even though construction managers may be aware of the existence of a potential cause of delay, they may not be able to accurately assess key issues like its full extent, its probable consequences, and whether or not it is likely to

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delay the project completion date. Construction managers, therefore, need appropriate tools to assist them in the process of updating the schedule based on the analysis of delays.

Several delay analysis methods, most of which are based on the calculation of the delay with respect to the project, have been discussed in the literature. Some of these methods include: a) the float allocation method; b) the net impact technique; c) the concurrent delay method; d)the as-planned method; e) the as-built (or traditional) method; f) the modified as-built method (or time impact analysis) g) the "but for" (or entitlement) schedule technique; h) the collapsed as-built method; i) the "snapshot" or "window" method of analysis; j) the daily windows delay method; k) the contemporaneous period analysis technique; and l) the delay section method (Trauner 1990; Alkass and Harris 1991; Revay 1994; Bubshait and Cunningham 1998; Finke 1999; Kartam 1999; Hegazy and Zhang 2005; Kim *et al.* 2005).

However, many of the studies on delay analysis methods have tended to ignore or not deal in detail with a consideration of the causes of the delays Among the few researchers who have considered causes of delays are Yates (1993), Assaf *et al.* (1995), Kumaraswamy and Chen (1996), Al-Momani (2000), Odeh and Battaineh (2002), and Assaf and Al-Hejji (2006). Yates (1993) presented a construction decision support system for delay analysis with the capability of determining possible causes for project delays, and suggesting alternative courses of action to prevent further delays. Assaf *et al.* (1995) studied the causes of delay in building projects in Saudi Arabia. They surveyed the main parties involved in construction activity and noticed that weather was a factor in construction delay. Al-Momani (2000) found in a study of 130 public projects in Jordan that weather was one of the main causes of delay in these projects. It stood along other factors such as delays related to designers, user changes, site conditions, late deliveries, economic conditions and increase in quantity. Assaf and Al-Hejji (2006) found that weather was also a cause of construction delay, hot weather being a significant issue for owners.

Based on the findings of these studies, it appears that weather conditions are likely to be significant sources of delays to construction schedules. This is because construction work, which is undertaken in the natural environment, is affected by weather events such as snow, hot and cold temperature, humidity, and rainfall. Delays as a result of weather conditions are therefore significant risk factors in the contract delivery process, and construction managers are often unable to reliably predict delays as a result of them. Thus, to calculate the expected duration of acceptable delays as a result of weather condition, a reasonable method, suitable for practitioners, for predicting schedule delays caused by weather conditions is necessary. In this study, we propose a method for calculating construction schedule delays where weather conditions are taken into consideration.

METHODOLOGY

The methodology for calculating schedule delay considering weather condition is based on the following steps:

1. Estimating the impacts of weather conditions on the project schedule;
2. Predicting weather condition using the data of the reliable source; and
3. Calculating schedule delay according to the impacts of weather condition on the different types of activities.

Estimation of Impacts of Weather Conditions

The extent to which adverse weather conditions affect a project will vary with a range of project related factors. Thus, the extent to which activity duration is impacted depends on the attributes of the activity that make it sensitive to the adverse weather. In line with the practical nature of the methodology proposed in this paper, three weather-sensitive attributes are considered for specifying the sensitivity of construction activities to weather conditions - a) "low", b) "medium", and c) "high". A low category represents activities that pose little or no problem due to weather condition. Conversely, a high category represents high impact of weather condition on activities.

It is recognized that different kinds of weather condition have different degrees of impact on project activities. In this paper, we have focused on three classifications of weather conditions to illustrate the principles of the methodology proposed in it. These classifications are snow, rain and cold temperatures. To illustrate the principles described in this paper, possible impacts of these particular weather conditions on project activities for each of the three sensitivity levels have been shown in Table 1.

As shown in Table 1, the sensitivity of the activity to the particular weather condition illustrates the extent to which the selected weather condition might impact on the project. This sensitivity will vary with factors such as geographical location of the project, the stage in the project at which the weather condition occurs, the actual activity being undertaken, and the exposure of the activity to particular weather conditions.

It should be noted that the estimation phase must be validated with historical data from real-world cases to achieve operational accuracy. It is therefore considered that in an actual contraction project the construction manager will be required to define, using judgment or expertise, the expected impact of weather conditions on the performance of project activities.

Table 1: Impact of weather condition on project activities

Weather Condition	Sensitivity	Comments
Snow	High	The activity should stop
	Medium	Increase the duration of activity by 30%
	Low	Increase the duration of activity by 10%
Rain	High	Increase the duration of activity by 20%
	Medium	Increase the duration of activity by 10%
	Low	No effects
Cold Temperatures	High	Increase the duration of activity by 10%
	Medium	No effects
	Low	No effects

Prediction of Weather Conditions

An accurate prediction of weather condition over the estimated life of the project is required for the estimation of schedule delay. Typical expected weather conditions may be obtained from historical data and weather forecasting reports. However, weather forecasting involves much uncertain information that is very difficult for managers to ensure that assumptions made at the time of prediction will occur. For this reason, it is suggested that construction managers consider the probability of occurrence of each classification of weather condition. In such an analysis, it is possible to consider the probability of occurrence of selected weather conditions such as snow, rain, and temperature effects.

While at a more sophisticated level such estimation might utilize a project risk modelling approach (see for example Chapman and Ward, 2003, pp. 169-202), at a practical level it is possible to employ a more simplified approach. Such an approach might employ making a distinction between the probability of snow, rain, and temperature effects based on long-term weather forecasts and historical records.

As an illustration of this approach, if over a historical time period it is known that typically 400 mm rain falls in spring and 200 mm rain falls in winter, we can assume at a practical level that the probability of occurrence of rain in winter will be half of that in spring. Figure 1 shows an example of the application of this approach to a typical weather forecast. In the example in this figure, the expected probability of snowing in January and February will at 30% be three times that of November, December, or March. Similarly, there would be expected in this example to be six months with cold temperatures.

Calculation of Schedule Delay

Based on the above approach, it is postulated that schedule delays may be calculated by using an expression similar to Equation (1) below. This equation combines sensitivity of project activities to a given weather condition classification, probability of occurrence of that weather condition and scheduled duration of the activity.

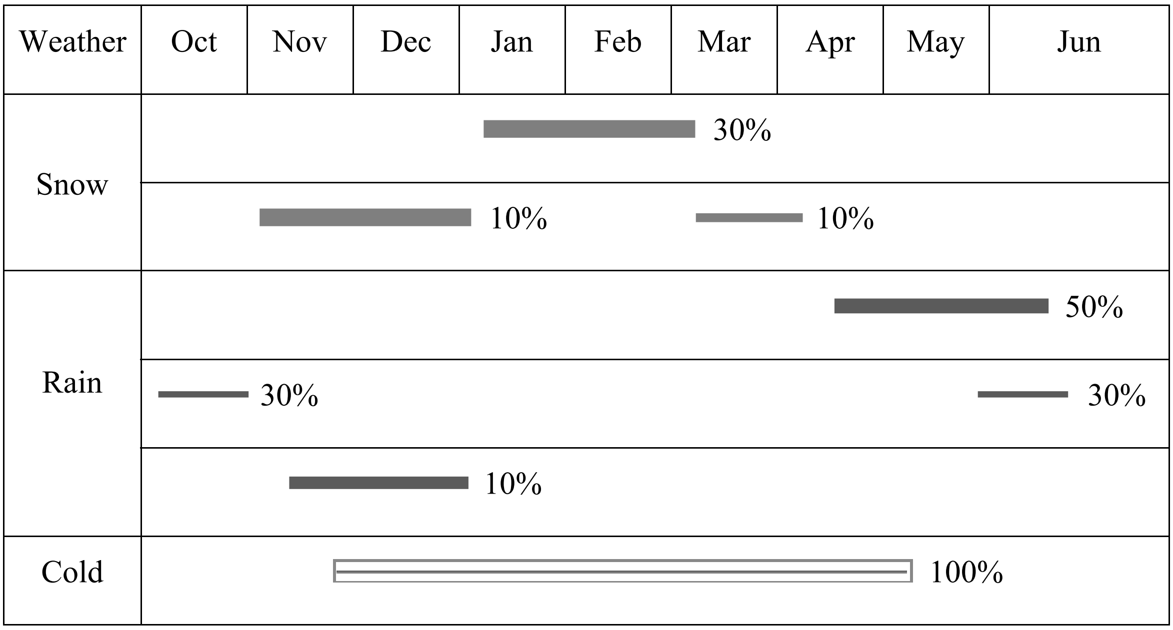

Figure 1: Prediction of weather

$$SD = \sum_{i=1}^{n} S_i \times P_i \times D_i \qquad (1)$$

Where SD=schedule delays, S_i=sensitivity factor of activity i based on its category, P_i=probability of occurrence of the weather condition, D_i=duration of activity i during the period of weather condition, and n=number of activities.

At the extremes, when an activity with high sensitivity occurs during high periods of snow, the impact on project activities would be 100% of duration during that time. Similarly, the expected impact for no adverse weather effect would be zero or 0%.

The calculation is carried out from the beginning of the first activity. It is necessary to determine the period of calculation steps. These steps are similar to the periods in which weather is forecast. For example, in Figure 1, the prediction of weather is defined in months. Therefore, the calculation of schedule delay for each activity is performed based on the different kinds of weather predicted for each month.

In the first step, we would determine the sensitivity of activity according to weather condition classification. Then, the duration of the activity in months (or other step scale) is determined. After calculating of schedule delay with Equation (1), the duration of the activity is modified to the new one. This process will be repeated for the following months over the life of the project.

In the next section, an example project is presented to demonstrate the computation procedure

EXAMPLE PROJECT

The following hypothetical residential building project is used to demonstrate the application of the proposed method. Figure 2 shows the as-planned bar chart schedule for the project, and Table 2 shows activity information such as level of sensitivity and their original duration. The as-planned duration of the project is 151 days. The weather prediction is assumed to be similar to that in Figure 1.

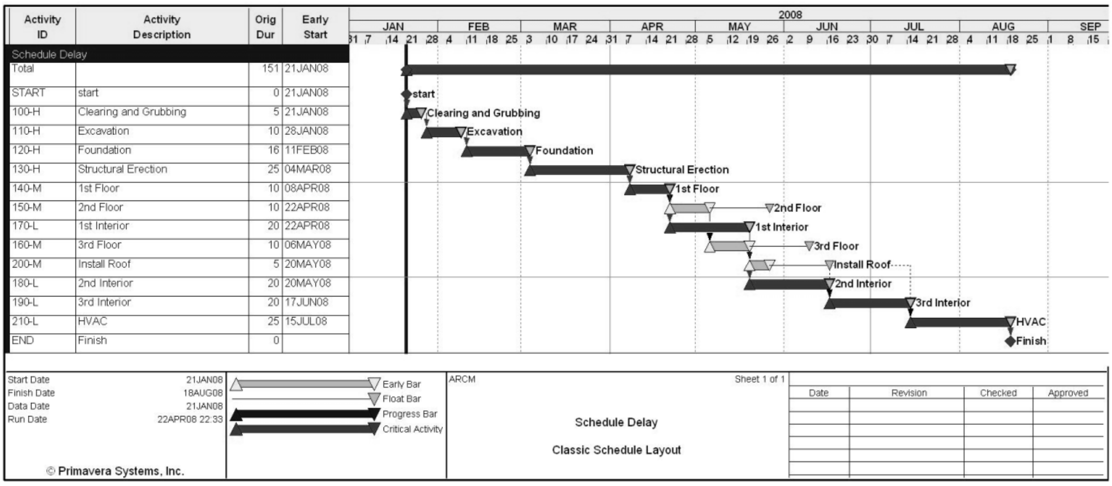

Figure 2: As-planned bar chart schedule for the example project

Table 2: Information of activities for the example project

Activity	Duration	sensitivity
clearing and grubbing	5 days	high
Excavation	10 days	high
Foundation	16 days	high
Structural erection	25 days	high
1st floor	10 days	medium
2nd floor	10 days	medium
3rd floor	10 days	medium
1st interior	20 days	low
2nd interior	20 days	low
3rd interior	20 days	low
install roof	5 days	medium
HVAC	25 days	low

The project starts on January 21, on which the first activity (i.e. clearing and grubbing) commences. In the as-planned schedule, *clearing and grubbing* is performed over five days (between January 21 and 26). In this period, there is snowy weather with a probability of 30% and cold temperature with a probability of 100%. Based on Figure 1, sensitivity of this activity to weather condition is high (100% for snow and 10% for cold).

The activity delay can be calculated using Equation (1):

$$SD_{clearing\ and\ grubbing} = \overbrace{(100\%)\times(30\%)\times 5}^{snow} + \overbrace{(10\%)\times(100\%)\times 5}^{cold} = 2\ days$$

As a result of the calculation the actual duration of this activity becomes (5+2) or 7 days as a result of weather conditions. In the next step, the new duration would be entered in the original schedule. For this study, the project schedule is represented with Primavera's P3 scheduling software. After changing the duration of *clearing and grubbing* from 5 to 7 days, the new schedule shown that the project duration becomes 153 days, and the second activity (i.e. excavation) starts on January 30 (see Figure 3).

Excavation is scheduled to be performed over 10 days. As with the first activity, there is snowy weather with a probability of 30% and cold temperature with a probability of 10%. The activity delay can be calculated as follows:

$$SD_{Excavation} = \overbrace{(100\%)\times(30\%)\times 10}^{snow} + \overbrace{(10\%)\times(100\%)\times 10}^{cold} = 4\ days$$

Therefore the duration of *excavation* changes to (10+4) or 14 days. Again, the new duration is entered in the schedule. Then, the new duration of the project changes to 157 days. Also the start time of next activity (i.e. foundation) changes from February 13 to 19 (see Figure 4). The process is continued until all activities have been considered.

Table 3 shows extended calculations of the schedule delay for the example project using similar principles. The total delays amount to 17 days, resulting in total project duration of 168 days, compared with 151 days without weather delays.

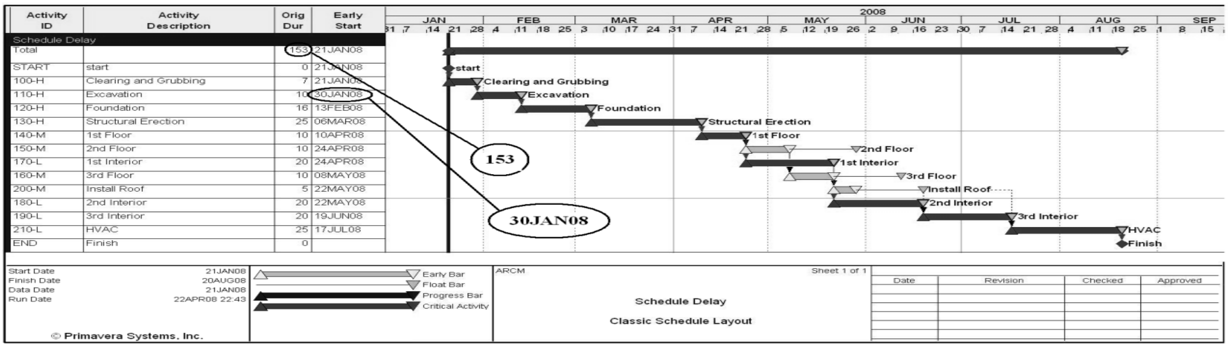

Figure 3: Bar chart schedule after changing the duration of first activity

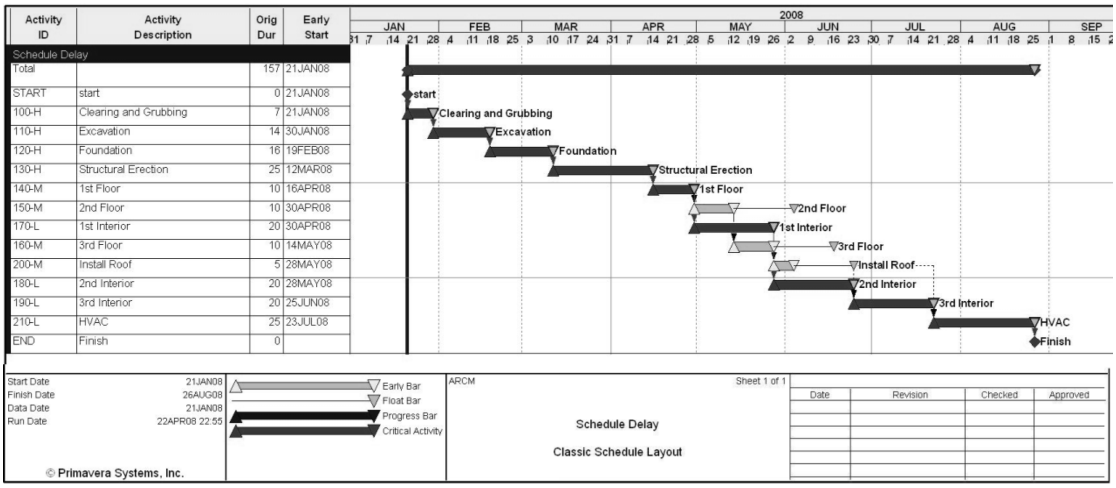

Figure 4: Bar chart schedule after changing the duration of second activity

Table 3: Calculation of the schedule delay for example project

Activity	Original Duration	Schedule delay	New Duration*
Clearing and grubbing	5 days	$(1\times 0.3+0.1\times 1)\times 5=2$	7 days
Excavation	10 days	$(1\times 0.3+0.1\times 1)\times 10=4$	14 days
Foundation	16 days	$(1\times 0.3)\times 9+(1\times 0.1)\times 7+(0.1\times 1)\times 16=5$	21 days
Structural erection	25 days	$(1\times 0.1)\times 9+(0.2\times 0.5)\times 16+(0.1\times 1)\times 25=5$	30 days
1st floor*	10 days	$(0.1\times 0.5)\times 10=0.5$	10.5 days
2nd floor*	10 days	$(0.1\times 0.5)\times 10=0.5$	10.5 days
3rd floor	10 days	$(0.1\times 0.5)\times 5+(0.1\times 0.3)\times 5=0.4$	10 days
1st interior	20 days	0	20 days
2nd interior	20 days	0	20 days
3rd interior	20 days	0	20 days
Install roof	5 days	0	5 days
HVAC	25 days	0	25 days

* Durations have been rounded to the nearest 0.5 day

APPLICATION OF THE METHODLOGY

As noted above, the proposed methodology provides a process to assist the prediction of the potential contract schedule delays as a result of weather conditions.

A second objective of this paper is to help planners to make decisions making regarding the optimum construction approach to meet the project schedule given expected weather conditions. To illustrate this process, different start times have been considered for the example project, and the proposed methodology was used to calculate their delay and their expected completion date. Figure 5 shows the application of this process to the example project. As shown in Figure 5, different project start dates may result in different project lengths under particular predicted weather conditions. When the project starts on February 4 its duration is 166 days and when it starts on 31 March, its duration is 159 days.

Although weather delays are typical of the so-called "act of God" type of delay, normal weather is not justification for the granting of an extension of time. Most general conditions of contract state specifically that only adverse weather conditions that cannot be reasonably anticipated would qualify as a basis for time extension (Halpin 2005). If construction managers provide a prediction of project length such as that shown in Figure 5, it can help them to make decisions making regarding the optimum construction approach considering weather condition delays.

This methodology also has the potential to be used by project owners and contract principals to assist them in their planning and design decisions, and help them make more reliable decisions with respect to options for the most effective delivery of a construction project. They would also benefit from optimizing the project start date as indicated in Figure 5, and in minimizing the uncertainty inherent in factors such as weather conditions. Such improved prediction of project duration has the potential to assist them to make better estimates of the expected delivery dates of projects.

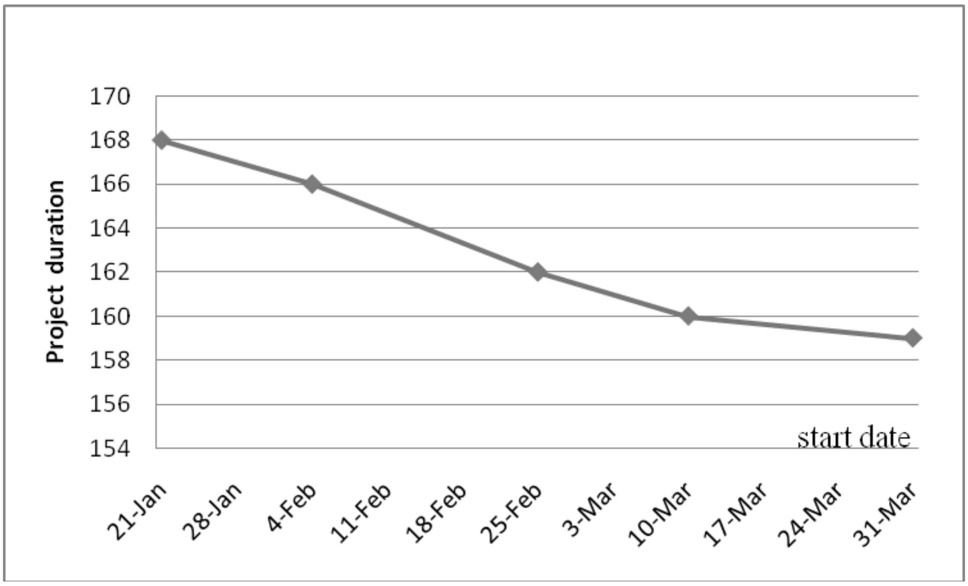

Figure 5: Duration of the project based on different start dates

Finally, this methodology has potential application in relationship contracts such as project alliances (for example, Thorpe and Dugdale, 2004). In such contracts there is a shared approach by principal and contractor to achieving project goals and sharing rewards. Better prediction of project duration as a result of weather condition has the potential to enhance target time and cost estimates for the alliance, and thereby provide an improved basis for evaluating rewards or penalties.

CONCLUSION

The methodology described in this paper has the potential to better enable all project participants to better evaluate the effect of weather conditions on the duration of construction projects with the aid of a practical tool, and thereby reduce uncertainly from the effects of weather, a factor which they cannot control. Such knowledge has the potential to assist contractors to make better estimates, enable project owners and contract principals to make a better estimate of project time, minimize disputes resulting from delays, and deliver cost savings as a result of less uncertainty with respect to duration of the project as a result of weather conditions.

While further research is required to evaluate and refine the methodology described in this paper, it is argued that it represents an important step in better predicting the likely time of a construction project given likely weather conditions, with resulting benefits for all parties involved.

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