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# Probabilistic Forecasting of Project Completion Date Using Material Status Onsite

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**Abstract:** This paper presents a newly developed method for forecasting project duration at completion and at any time horizon. The method is driven by the material status onsite using Material Status Index. This index is calculated based on the ratio of actual versus planned quantities of materials in place. The method heeds to the fact that activities don't impact project schedule status to the same degree. The concept behind the developed method is that material can be seen as the fuel that provides the energy needed to propel projects from commencement to completion. This forecasting method utilizes seventy eight material based factors recognized to cause schedule delays. These factors were reported in a number of studies and are referred to here as probable causes. They cover the supply chain material management before material reaches the site, once material is at the gate prior to acceptance and finally onsite. A simulation model is then created utilizing users judgment on the applicability of these probable causes to the project at hand. The simulated model serves as input to the forecasting function, which delivers a probability distribution of the forecasted project duration. A numerical example of a hydro power station is utilized to illustrate the capabilities of the present method. The analysis of the case considered, demonstrates the enhanced capabilities provided by the developed method to the traditional EVM. The introduced enhancements are demonstrated on two fronts; accuracy in forecasting, and the consideration of the risks involved.

## Introduction

One of the essentials of project control success is the ability to forecast the future of project status in a timely manner. Through the conventional Earned Value Management (EVM) method, there are three approaches to forecast duration of projects: planned value method (PVM) (Anbari, 2003), earned schedule method (ESM) (Jacob, 2003) and earned duration method (EDM) (Lipke, 2003). A number of studies indicates that the earned schedule method of forecasting provides more accurate results in predicting time at completion of project (Vandevoorde & Vanhoucke, 2006) (Kim, 2007) (Lipke, 2009) (Vanhoucke, 2011) (Moselhi, 2011). Over the years, considerable studies have been conducted to improve the accuracy of these forecasting methods through deterministic or stochastic approaches. Some researchers attempted to provide strategic consideration of project deliverables. Hassanein (Hassanein & Moselhi, 2003) suggested shifting the focus from activity level to crew level, when forecasting; and assigning different weights to different periods of crew performances. Moselhi (Hassanein & Moselhi, 2003) (Moselhi, 2011) suggested to blackout periods experiencing accidents or exceptional conditions that are not likely to reoccur in the future. However many have speculated on the fact that, the fundamental principles of earned value forecasting are that, the best available indicator of the future performance remains to be the past performance (Christensen & Heise, 1993) (Zwikael, et al., 2000) (Kim

& Reinschmidt, 2010). Christensen (christensen, 1992) introduced a generic index based formula to forecast estimate at completion. Li (Li, 2004) expanded on it and categorized these formulas in 7 different scenarios, which would deliver different indices used to adjust schedule and/or cost performance of project to date. A number of researchers delved to find different variations of correction factors. Alshibani (Alshibani, 1999) introduced "management and job conditions factors" to the existing SPI and CPI metric to be used in forecasting final time and cost. However, he failed to introduce any specific range of values for the proposed coefficients. Moselhi (Moselhi, 2011) presented an incrementally adaptive learning model for forecasting duration where the forecasting function is adjusted by a factor attained from the difference in forecasted and actual values from the previous period. Moselhi and Xiao (Moselhi & Xiao, 2011) used a forecasting formula of an industry partner to enhance the accuracy and took into account projects' objective performance criteria that would not change from an expert judgment to another. Their contribution was in transforming a purely judgmentally based forecasting formula to a less objective method to calculated time and cost at completion.

A good forecasting technique is one that contains both the historical trend-based data and competent judgments based on construction experience and knowledge (Al-Tabtabai, Hashem; Diekmann, James E.;, 1992). To date, no method satisfactorily addressed the issue of objective user judgment in forecasting. The proposed method is aiming to adjust the schedule performance resulted from the material status onsite in a way that adds a less subjective layer of project expert judgment to the conventional forecasting master formulas. The contribution of the model is mainly in offering the user, a set of causal factors that may delay project schedule due to material management cycle. Since materials are the very main components of the physical progression of construction onsite, the performance metric utilized in the forecasting formula is the Material Status Index (MSI) and subsequently the causal factors are those affecting material installation on site.

In this respect, a comprehensive literature review was carried out to find what material related drawbacks could possibly occur. These factors are attributed to procurement cycle and utilization of material on site. This study led to compiling a set of 78 causal factors that are likely to cause schedule delays. These causal factors are grouped under three categories: supply chain- before material reaches the site, staging area- at the gate before acceptance and on site- after acceptance. To better map under which functions these factors are found, they are arranged into a hierarchical structure. These categories represent the first tier of the hierarchy followed by second and further tiers, where the last tier of this structure includes the causal factors. Due to space limitations, only the onsite tier of the causal factors hierarchy is presented in this paper (Table 1).

## Proposed Method

### 1 Material Status Index

The proposed forecasting method utilizes the material status index (MSI) developed by the authors elsewhere. Brief description of MSI is provided here for continuity. Materials are seen to serve as fuel to construction projects and also the main constituents of physical progress of projects. That is why quantities of materials in place are deemed to best serve as indicators of the schedule performance. However, materials bear different units and counting natures hence they cannot be all represented by one single index directly. Therefore, MSI is calculated at material level in the first step and then based on a user defined relative weights they can be aggregated into one single index that is representative of the total project status. As discussed earlier, material status index enhances the reliability of the reported schedule performance by accounting for the criticality and level of influence of activities on project status.

Table 1: Causal factors on site

| Area | Sub Area 1 | Sub Area 2 | Causal factor |
|---|---|---|---|
| On site | Storage | Others | Unavailability of right equipment |
| | | | Storing materials in temporary craft |
| | | | Unavailability of right crew |
| | | | storage areas, shacks, gang boxes and staging areas |
| | | | Materials improperly sorted or marked |
| | | Open storage sites | Insufficient know ledge of on-site stock |
| | | | Inability to determine material locations |
| | | | Insufficient storage area due to site congestion |
| | | | Insufficient provisions for laying materials |
| | | Warehouse | Lack of w arehousing facilities |
| | | | Insufficient know ledge of quantities |
| | | | Problems w ith w arehouse requisition obtentions |
| | | | Lack of security and access control |
| | Handling | Insufficient rigging requirements | |
| | | Inexperienced w orkforce | |
| | | Extensive multiple handling of materials | |
| | | Trash or debris obscuring access to materials | |
| | Waste | Deterioration | |
| | | theft | |
| | | loss | |
| | | Inaccurate quantification of change orders | |
| | | Natural catastrophes | |
| | Installation | Unavailability of right equipment | |
| | | None supply of manifest or erection documents by supplier | |
| | | Unavailability of right crew<br>Inexperienced w orkers | |
| | | Crew slow dow n in anticipation of material shortage | |
| | Others | Inadequate identification of materials to designated subs | |
| | | Material related paperw ork | |
| | | Remobilization and refamiliarization after a lengthy delay | |

Individual MSIs are the explicit installation performance indicators of the past. The theory behind the proposed forecasting methods lies in the adjustments of the calculated individual MSIs associated with each material considered. Such adjustments account for future uncertainties pertaining to each material, based on user judgment. To decrease the subjectivity of users' judgments the generic list utilized in the developed method is presented to help in selection of the applicable causal factors.

Traditional EVM and the related three forecasting methods referred to earlier are deterministic and do not provide any information about the range of possible outcomes and the probability of meeting project objectives (Kim & Reinschmidt, 2010). Therefore, Instead of a single point estimate of project duration, the present method provides a probabilistic estimate of project duration at completion and at any time horizon using Monte Carlo simulation to model the uncertainties associated with the impact of the causal factors on project schedule delay. The procedure taken in forecasting using MSI is explained in figure 1.

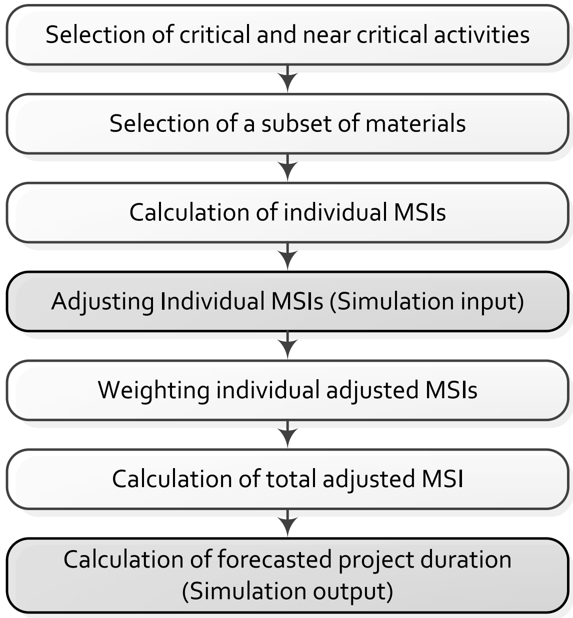


Figure 1: Forecasting procedure

## 2 MSI's forecasting module

### 2.1 Selection of materials

Essentially, there is a certain number of activities that dominates schedule performance at each report date. That is why the first step in calculating project duration at completion is, to choose those materials that are the drivers of schedule performance. It is obvious that the total float and its proportion to the duration of activity are the main determinants of such impacting activities. However, some project dependent factors can become a determining agent at times, which the user should be able to pick from the list of materials as well.

### 2.2 Calculating individual MSIs

Upon selecting the materials used in the set of selected activities, MSI is calculated based on actual vs. planned quantities of materials in place. It should be noted that, the material considered in the calculation can be consumed by one or more activities. That is to say quantities considered in the MSI calculation are what all activities consume.

[1]

$$MSI_m = \frac{\sum_{i=1}^{n} InsQa}{\sum_{i=1}^{n} InsQp}$$

Where InsQa is the actual installed quantity; and InsQp is the planned installed quantity.

### 2.3 Adjustment of individual MSIs

Each individual material status index is then adjusted to account for uncertainties. These uncertainties are identified by the user from the list of 78 causal factors. The expected impact of each identified causal factor per selected material is next assigned within a range. The maximum and minimum values of that range vary from 0.0 to 1.0. These values are then used to describe a symmetrical triangular distribution used subsequently as input for the Monte Carlo simulation. These minimum and maximum values can be negative or positive to represent threats and opportunities, which indicates that the MSI used in forecasting is worst or better than the MSI so far achieved. In view of the fact that each of the 78 causal factors, if happened during the course of construction, has the potential of impacting project completion date to any degree, their joint impact factor (R) is calculated through the simulation process. In this process R is calculated as weighted average of the individual expected impacts. The adjustment of respective individual MSIs are calculated Equation in equation 2.

[2]
$$A - MSI_m = MSI_m * (1 + R_m)$$

Where A-$MSI_m$ is the adjusted MSI for the material m, $MSI_m$ is the material status index of material m, R is the average expected impact of all selected causal factors for material m.
A negative R value demonstrates a delay beyond that experienced up to this reporting period whereas a positive value indicates improvement over the cumulative performance achieved up to this reporting period.

## 2.4 Adjusted total MSI

To obtain a total material status index for the whole project, rather than for a number of activities which consume a common type of material, a weighting summation should be deployed.

[3]
$$A - MSI_t = \sum_{m=1}^{n} (A - MSI_m * W_m)$$
Where A-MSIt is the adjusted total MSI for material m and Wm is the relative weight of material m.

## 2.5 Forecasted duration

Duration at completion or any interim time horizon can be easily attained from adjustment of the schedule performance that is not only indicative of the past but also the future of project (adjusted total MSI).

[4]
$$Forecasted\ Duration = D_F = \frac{D_o}{\mathrm{A - MSI}_t}$$

Where $D_o$ is the original duration. A probabilistic model as the forecasted duration of project will be the simulation output implemented.

## Numerical Example

The presented method is implemented on a real project of a hydro power station constructed in northern Quebec. The 2 year long project data was changed at a number of locations to respect confidentiality. As well, a number of scenarios were generated to demonstrate the use of the developed method and to illustrate its capabilities. The following characterizes, respectively, each of the three scenarios:

- Consider critical activities and all their respective materials.
- Near critical and critical activities considering all their consuming materials

- Near critical and critical activities considering a subset of materials

The reporting period is considered at month 12 for the three scenarios. All activities are considered to have proceeded according to schedule. However, two originally near critical activities whose duration-total float ratio indicates higher potential to cause schedule delays are steered in a way to move project duration further away from that planed. Consequently, this process triggers a new critical and near critical path depending on the job logic that would better satisfy the inclusiveness objective of this case study. Introduced enhancements are demonstrated on two fronts; accuracy in forecasting, and the consideration of the risks involved. Summary of scenarios, interim calculations and output results are presented in the tables 2- 7.

Table 2: Causal factors considered per material-Scenario 1

| Risk factor for | MSI1 | Opportunities | | |
|---|---|---|---|---|
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 0.200 | 0.300 | 0.400 | 0.300 |
| **F2** | 0.100 | 0.250 | 0.400 | 0.250 |
| **F3** | 0.100 | 0.100 | 0.100 | 0.100 |
| **F4** | 0.500 | 0.700 | 0.900 | 0.700 |
| **F5** | 0.300 | 0.325 | 0.350 | 0.325 |
| **F6** | 0.900 | 0.950 | 1.000 | 0.950 |
| **F7** | 0.010 | 0.505 | 1.000 | 0.505 |
| **Aggregate(Mean)** | | | | 0.447 |
| Risk factor for | MSI2 | Delays | | |
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 0.100 | 0.250 | 0.400 | 0.250 |
| **F2** | -0.800 | -0.700 | -0.600 | -0.700 |
| **F3** | -1.000 | -0.500 | 0.000 | -0.500 |
| **F4** | -1.000 | -1.000 | -1.000 | -1.000 |
| **F5** | -0.500 | -0.350 | -0.200 | -0.350 |
| **Aggregate(Mean)** | | | | -0.460 |
| Risk factor | MSI3 | No change | | |
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **Mean** | | | | 0.000 |

Table 3: Causal factors considered per material-Scenario 3

| Risk factor for | MSI1 | Opportunities | | |
|---|---|---|---|---|
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 0.200 | 0.300 | 0.400 | 0.300 |
| **F2** | 0.100 | 0.250 | 0.400 | 0.250 |
| **F3** | 0.100 | 0.100 | 0.100 | 0.100 |
| **F4** | 0.500 | 0.700 | 0.900 | 0.700 |
| **F5** | 0.300 | 0.325 | 0.350 | 0.325 |
| **F6** | 0.900 | 0.950 | 1.000 | 0.950 |
| **F7** | 0.010 | 0.505 | 1.000 | 0.505 |
| **Mean** | | | | 0.447 |

Table 4: Causal factors considered per material-Scenario 2

| Risk factor for | MSI1 | Opportunities | | |
|---|---|---|---|---|
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 0.200 | 0.300 | 0.400 | 0.300 |
| **F2** | 0.100 | 0.250 | 0.400 | 0.250 |
| **F3** | 0.100 | 0.100 | 0.100 | 0.100 |
| **F4** | 0.500 | 0.700 | 0.900 | 0.700 |
| **F5** | 0.300 | 0.325 | 0.350 | 0.325 |
| **F6** | 0.900 | 0.950 | 1.000 | 0.950 |
| **F7** | 0.010 | 0.505 | 1.000 | 0.505 |
| **Mean** | | | | 0.447 |
| Risk factor for | MSI2 | Delays | | |
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 0.100 | 0.250 | 0.400 | 0.250 |
| **F2** | -0.800 | -0.700 | -0.600 | -0.700 |
| **F3** | -1.000 | -0.500 | 0.000 | -0.500 |
| **F4** | -1.000 | -1.000 | -1.000 | -1.000 |
| **F5** | -0.500 | -0.350 | -0.200 | -0.350 |
| **Mean** | | | | -0.460 |
| Risk factor | MSI3 | No change | | |
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **Mean** | - | - | - | 0.000 |
| Risk factor for | MSI2 | Opportunities | | |
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 0.100 | 0.250 | 0.400 | 0.250 |
| **F2** | 0.600 | 0.700 | 0.800 | 0.700 |
| **F6** | 0.800 | 0.900 | 1.000 | 0.900 |
| **F7** | 0.010 | 0.505 | 1.000 | 0.505 |
| **Mean** | | | | 0.589 |
| Risk factor | MSI3 | Opportunities | | |
| | **Min** | **Most Likely** | **Max** | **Defined dist.** |
| **F1** | 1.000 | 1.000 | 1.000 | 1.000 |
| **Mean** | | | | 1.000 |

Table 5: Adjustment of individual MSIs and calculation of forecasted duration- scenario 1

| | **Individual MSI** | **Risk Factor** | **Adjusted Individual MSI** | **Weight** | **Weighted adjusted individual MSI** | **Scenario 1** |
|---|---|---|---|---|---|---|
| **Form** | 0.371 | 0.447 | 0.537 | 1.000 | 0.537 | |
| **Concrete** | 0.471 | -0.460 | 0.254 | 1.000 | 0.254 | |
| **Rebar** | 0.500 | 0.000 | 0.500 | 1.000 | 0.500 | |
| **Adjusted Total MSI (weighted average)** | | | | 0.430 | | |
| **$D_{original}$** | | | | 830.000 | | |
| **$D_{forecasted}$** | | | | | | 1928.217 |

Table 6: Adjustment of individual MSIs and calculation of forecasted duration- scenario 2

| | Individual MSI | Risk Factor | Adjusted Individual MSI | Weight | Weighted adjusted individual MSI | Scenario 2 |
|---|---|---|---|---|---|---|
| **Form** | 0.371 | 0.447 | 0.537 | 1.000 | 0.537 | |
| **Concrete** | 0.471 | -0.460 | 0.254 | 1.000 | 0.254 | |
| **Rebar** | 0.500 | 0.000 | 0.500 | 1.000 | 0.500 | |
| **Scaffolding** | 0.371 | 0.589 | 0.589 | 1.000 | 0.589 | |
| **Ribbed PVS** | 0.371 | 1.000 | 0.742 | 1.000 | 0.742 | |
| **Adjusted Total MSI (weighted average)** | | | | 0.524 | | |
| **$D_{original}$** | | | | 830.000 | | |
| **$D_{forecasted}$** | | | | | | 1582.579 |

Table 7: Adjustment of individual MSIs and calculation of forecasted duration- scenario 3

| | Individual MSI | Risk Factor | Adjusted Individual MSI | Weight | Weighted adjusted individual MSI | Scenario 3 |
|---|---|---|---|---|---|---|
| **Form** | 0.371 | 0.447 | 0.537 | 1.000 | 0.537 | |
| **Adjusted Total MSI (weighted average)** | | | | 0.537 | | |
| **$D_{original}$** | | | | 830.000 | | |
| **$D_{forecasted}$** | | | | | | 1546.490 |

Comparing the simulation outputs of the three scenarios reveals, as shown in Table 10, that scenarios 2 and 3 display more similar results whereas in scenario 1, results are further away from the other two, due to differences in the overall values of the adjustment factor. It should be noted that the number of causal factors under study for each material is not a driving factor but rather is their expected impact.

Apart from the effect of the R factor on the forecasted duration of the project, is the noticeable difference of forecasted durations calculated by MSI and SPI. Forecasting project duration using SPI can result in misleading project schedule status and erroneous forecasted duration. SPI would not heed to the criticality of activities involved in the project and treats all activities equally. This is why real project performance is sometime masked by the performance of non-critical activities that are none influential to

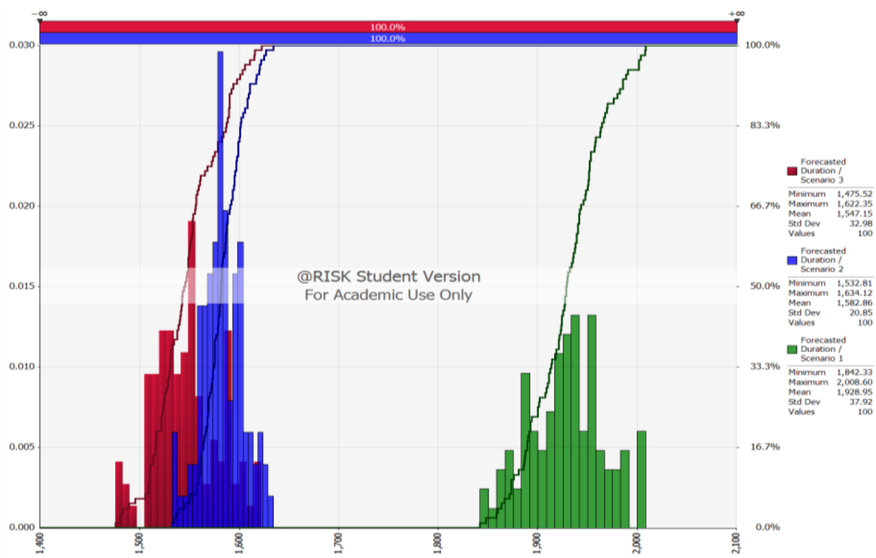


Figure 2: Forecasted duration distribution models of the three scenarios

project duration. Forecasting duration of project using MSI is more accurate because of its consideration of level of criticality of project activities. In addition, the adjusted MSI provides a less subjective platform for the decision makers to account for risk.

Table 8: R factor comparison of the three scenarios

| | R Factor | | |
|---|---|---|---|
| | **Scenario 1** | **Scenario 2** | **Scenario 3** |
| **Material 1** | 0.447 | 0.447 | 0.447 |
| **Material 2** | -0.460 | -0.460 | - |
| **Material 3** | 0.000 | 0.000 | - |
| **Material 4** | - | 0.589 | - |
| **Material 5** | - | 1.000 | - |
| **Average** | -0.013 | 0.315 | 0.447 |

Table 9: Duration comparison of the three scenarios

| **$D_{forecasted}$** | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| **$MSI_t$- Adjusted (Mean)** | 1928.217 | 1582.579 | 1546.490 |
| **$MSI_t$** | 1855.058 | 1991.351 | 2174.055 |
| **SPI** | 897.333 | 897.333 | 897.333 |

## Summery and Concluding Remarks

A newly developed forecasting method is presented to enhance and supplement the existing earned value forecasting formulas. These enhancements are made possible through the consideration of activity criticality and uncertainty in forecasting. The use of the set of causal factors is expected to reduce the subjectivity associated with direct adjustment of calculated MSIs.

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