Material Status Index In Support Of EVM

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ABSTRACT

Material can be seen as the fuel needed to execute the project from inception to completion. Material installed provides good indicators of progress achieved onsite vis-a-vis project schedule performance. It correlates well with the role of the schedule performance index (SPI) of the earned value method (EVM). Material is recognized to have a significant impact on achieved progress for physical completion of project activities. This paper presents a study on the development of material status index (MSI) in support of the EVM. Unlike the SPI, the newly developed index account for the criticality of project activities. This is carried out considering the total float of each activity, percent float (i.e. the ratio of float to activity duration) and the total float of the path on which the activity is located. MSI, can independently and jointly with SPI provide root causes behind problems encountered during project execution. In turn MSI can reveal material related factors behind the performance detected by joint interpretation of the two indices. MSI serves to provide added value in alerting management to take corrective actions. While SPI and MSI may have different values, they can jointly augment and enrich the captured project status based on EVM. To demonstrate the capabilities of the developed MSI method, it is implemented on a case study. The case encompasses the construction schedule of a hydro power station constructed in northern Quebec. Different scenarios are adapted from the real case to demonstrate a set of practical aspects of the developed index. The results generated from the analysis of the case study illustrate the useful features of MSI beyond those of the traditional SPI on two fronts; causation and the considerations of criticalities of actives.

KEYWORDS

Material Status Index, Schedule Performance Index, critical activities, EVM, material management

INTRODUCTION

To ensure whether projects are progressing as planned, and to plan ahead for the future actions during execution period, their surveillance is a must. The C/SCSC (Cost Schedule Control System Criteria), also known as earned value method (EVM), initiated by the US Department of Defense (DoD) has been the most well-known control technique presented since 1960s. EVM brings cost and schedule variances analysis together to provide managers with a more accurate status of a project (Kim , et al., 2003). However, many researchers have critiqued and introduced extensions to improve the accuracy and application of EVM metrics over the years. Some argued that schedule measures of earned value management are flawed, for EVM delivers schedule variance and index in terms of monetary values (Lipke, 2003; Anbari, 2003; Lennon, 2010; Moselhi 2011)

Contrary to the schedule metrics of EVM, its cost performance related metrics have been less often found under the spotlight of debates on accuracy. This is mostly due to the fact that cost possesses an additive quality by nature; regardless of the criticality of the activities involved; for all cost items are summed up in the process of delivering an overall project cost performance. However, the additive attribute does not apply to time and schedule, and equal treatment of activities when considering schedule performance is erroneous. (Short, 1993; Project Managemnet Institute, 2008; Moselhi 2011). Moselhi (2011) further suggested blacking out non indicative periods when calculating schedule performance index for forecasting purposes. He proposed focusing on critical activities rather than all activities as non-critical ones may mask the real performance of the project.

Vanhoucke & Vandevoorde, 2008, also confirmed that small delays in critical activities coupled with much faster progress in non-critical activities can lead to false SPI values. The process of tracking and evaluating project status on every and each of activities involved in the project is burdensome, especially in detailed schedules where the number of activities are in the thousands. Vanhoucke, 2009, stated that the sole working approach for practitioners is to consider activities on higher WBC levels to deal with a much more achievable number of activities. Lipke et al. (Lipke, et al., 2009) also noted that a detailed schedule analysis would create heavy load and undue demanding effects on the project team.

Proposed METHOD

Material Status Index is a newly developed index, aimed to augment existing EVM indices. It measures the schedule performance of projects using the quantity of material in place which is the main components of progress achieved on site. Materials play the role of fuel to construction projects. Thus, alternatively, project progress can be directly evaluated through the quantities of materials installed to provide a sensitive thermometer that articulates the status of onsite work progress. To achieve continuous rather than discrete schedule status of project through material consumption, close monitoring of material quantities is required. This is important in view of the fact that the accuracy of EVM indices is greatly dependent on the frequency of actual data acquisition from construction job sites. Integrating the state of the art technologies in tracking materials onsite and the developed MSI method allows for such needed continuity.

Aside from continuity, the MSI developed in this study accounts for the degree of activity criticality. A procedure is developed to select the impacting activities and their respective materials. As such, not all project activities and not all material for the selected activities are used in calculating the value of MSI. Considering that materials have different units of measurement, they cannot all be indexed directly into one function. The emphasis here is placed on materials rather than activities in the development of MSI. Therefore, quantities of each material consumed by all activities to date are tracked in the first step and subsequently a composite value is calculated based on the importance of each individual material to the project duration. Figure 1, depicts the procedure taken in the MSI calculation.

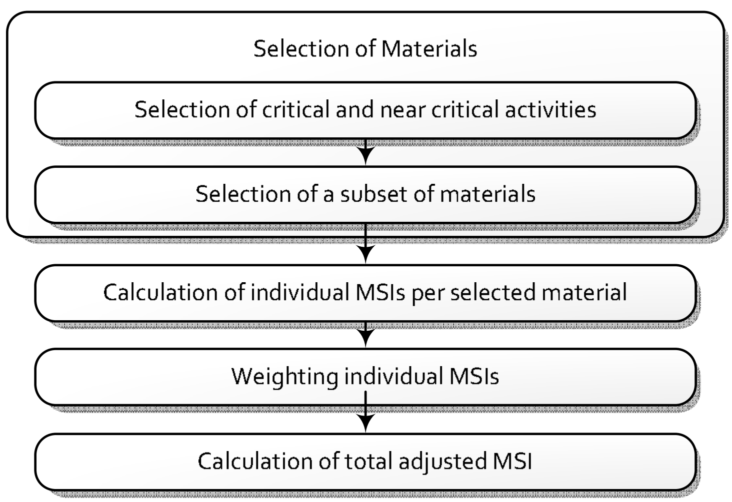

Figure 1- The procedure to calculate MSI

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In the conventional SPI procedure, calculations are on the activity level. However, materials serve as the control points in MSI method. The material status index follows the actual vs. planned principle of EVM performance indices with a further focus down to the components of activity progress. It should be noted that, the complete process should be carried out, each time MSI is reported during the execution of project as materials being used by in-progress activities change as well as activities over time. MSI captures the dynamically changing nature of material consumption onsite; as new materials get introduced and others disappear from the enlisted materials for construction.

Selection of Materials

In the proposed method, material in-place is indicative of a set of activities that consume those particular materials. Thus, criticality of materials is implicitly dependent on the criticality of their consuming activities. That is, the more critical an activity is, the more critical the materials used by that activity become. Criticality is accounted for, considering two main attributes, the total float and its ratio with the duration of activity. Total float provides a measure demonstrating that activities don't impact project duration and therefore schedule performance as long as they don't get delayed beyond their total floats. That is to say, criticality of an activity represents that of its material(s) and both are in direct relation with its total float. Total float to duration ratio augments the total float measure in cases where more than one activity has the same total float but with different durations. It accounts for the fact that an activity (or material) with the longer duration is relatively more likely to get delayed under normal identical circumstances.

In the process of selection of materials for MSI calculation, both conditions are evaluated to ascertain whether or not to include a material in the computation process. This process reduces considerably the number of activities involved for computation. The primary objective of this process is to avoid the masking effect of non-critical activities on the real performance of project. As well, this rational selection process allows for a much more manageable set of control points to concentrate on while not comprising inclusion of vital details to project performance. This selection procedure, however, is not similar to the use of higher WBS levels to alleviate the computation intensity.

Near critical activities can also become influential on project duration. Therefore, there should be a mechanism that specifies which activities should and should not be included in performing MSI calculations. Since construction projects are of dynamic nature and schedules are designed in a way to accommodate specific needs of each individual project; while abiding by the core objectives of the method, a single threshold that works for all, to ascertain inclusion or exclusion cannot be suggested. This decision should be project specific and even specific to each period of projects. That's why the user, being considered, knowledgeable of the project should be able to introduce the criticality threshold according to the particular conditions of the construction job at hand. This threshold can be expressed in terms of a percentage of activity or project duration and it determines the first subset of materials. In addition to the consideration of activity criticality, the developed method accounts also for the criticality generated by the logistics and risks associated with materials even if related to non-critical activities. This is implemented making direct use of the project bill of material and from there on, another round of further filtering of materials is undertaken to form the most indicative materials of the schedule performance.

Individual MSI

Material status index is a material driven indicator, which measures the compliance of actual performance to that of planned material installation onsite. This index is representative of schedule performance of project. Upon selection of materials, all activities that consume the same material are clustered together to be represented by an individual MSI for that specific material. It should be noted that in rare cases a material may be consumed by both critical and non-critical activities, which may influence the accuracy of the generated MSI in detecting the schedule performance.The ratio of summation of actual material quantities installed up to the reporting date of all activities consuming material m, over summation of planned material quantities of the selfsame tasks is termed material status index.

1) $$MSI_m = \frac{\sum_{i=1}^{n} InsQ_a}{\sum_{i=1}^{n} InsQ_p}$$

Where $InsQ_a$ is the actual installed quantity; and $InsQ_p$ is the planned installed quantity.

The planned installed quantity is determined from an integrated schedule of material takeoff and project schedule; that is, the gradual consumption of materials through project execution, derived from project blueprints. If project is benefiting from a BIM model, for example, the installation schedule is automatically generated from its 4D model.

Tracking actual installed quantities is a more challenging task to fulfill. Materials are brought to the site on a timely basis, according to the replenishment schedule and inventory system established by material managers. Traditionally, superintendents manually take note of the time, quantity, and quality of delivered material. Such manual process is error prone and time consuming. Tracking actual quantities of material in near-real-time is becoming more convenient than ever before in view of the current advancements in automated site data acquisition using technologies such as RFIDs and other remote sensing technologies. Utilizing these tools, the flow of materials in and out of construction sites can be tracked. The location of materials can be identified with ease and based on that, quantity installed can be automatically calculated.

The net consumption of materials by the project is the total replenished quantities minus quantities remained, i.e. residing in open storage areas or warehouses. There should be a pronounced distinction made between consumption and installation. Consumption is composed of two parts: wasted and installed constituents. Waste is generated due to inapt selection of equipment, inefficient handling or installation of materials, unskilled labors, deterioration of goods because of deficient environmental protections, residuals resulted from limited material fabrication onsite, incidents on site, change orders, reworks, etc.

A significant effort is made in the domain of waste creation, quantification and lean practices associated with this subject (Gavilan & Bernold, 1994) (Jalali, 2007) (Cha, et al., 2009) (Poon, et al., 2009). Yet, since waste generation is highly dependent on the aforementioned causes, waste quantities commonly differ from site to site and constructor to constructor. On average, waste quantities are considered to be within 10%-15% of the total installed quantity (Logislative council panel of the HKSARG, 2006). This ratio deducted from the consumed quantities, provides a reliable value of the installed portion. The portion of material consumption, which contributes towards project progress, is counted as installed.

2) $$InsQa = ConQa - W$$

Where $InsQ_a$ is the actual installed quantity; $ConQ_a$ is the actual consumed quantity; and W is the waste quantity.

Total MSI

Total MSI indicates the overall schedule performance of projects as opposed to material specific index that the individual MSI represents. Selected materials for the use of MSI calculation are a critical subset of entire set of materials used in a project. Thereby, allocation of an equal weight to each individual MSI is a reasonable treatment towards the initially selected set of materials, and their consolidation into one index.

3) $$MSI_t = \frac{\sum_{m=1}^{n}(MSI_m)}{n}$$

The critical threshold of MSI_t remains to be 1, analogous to SPI. A total MSI value equal to one, indicates that project performance is on schedule, and a value less than 1 is indicative of a schedule performance less than desired while a MSI_t greater than 1 is a sign of good schedule performance.

Joint Interpretation of MSI and SPI

Material Status Index is comparable to the Schedule Performance Index of EVM. Depending on different conditions of the project at hand, MSI and SPI may have equal or different values However, the added value in utilizing MSI lies in those cases where MSI and SPI differ and therefore MSI can point at the root cause of schedule slippage. The following six scenarios can occur regarding MSI and SPI.

1.	MSI>1 and SPI>1 :	Project is ahead of schedule
2.	MSI<1 and SPI<1:	Project is behind schedule
3.	MSI=1 and SPI=1:	Project is on schedule
4.	MSI>1 and SPI≤1:	Project ahead of schedule but attention should be drown to non-critical activities that are becoming critical Attention should be drawn to escalation in cost of resources
5.	MSI<1 and SPI≥1:	Project behind schedule but SPI displays misleading results due to its failure to capture criticalities of activities and because the real status of project is masked by the performance of non-critical activities
6.	MSI=1 and SPI≠1:	Project on schedule but SPI delivers misleading results due to its failure to capture criticalities of activities and because the real status of project is masked by the performance of non-critical activities

Case Study

A numerical example is presented here to demonstrate the enhancements introduced by MSI in reporting the status of the project schedule. The data for the example is obtained from construction of the concrete structure of a hydro power station in north of Quebec. The project is comprised of 134 activities concerning concrete work for the foundation and superstructure as well as mobilization to the jobsite. A number of scenarios are generated to illustrate the capabilities of the developed method. The following describes each of the three scenarios, respectively:

- Critical and near critical activities considering selected material
- Critical and near critical activities considering all their material
- Critical activity considering selected material

The report date is considered to be at the 12th month of the two-year-long project duration. All activities are assumed to have progressed according to schedule. However, a few originally near critical activities whose total float-duration ratio is relatively of a smaller value and as a result prove to be more prone to affect project duration if ever delayed, are steered in a way to extend beyond their total floats. Such modeling of project activities leads to creation of one or more new critical paths which is considered for this study and is different than the originally planned critical path. The process explained in the body of the paper along with the results obtained for the above stated three scenarios are presented in Table 1-4

Table 1- Considered activities and their consuming materials data

Attributes	Activities			
Activity ID	C130*	J130	J120	J110*
Activity Status	In Progress	In Progress	In Progress	In Progress
Total Float	-82	20	20	20
Original Duration	380	320	280	200
Total float/duration	-0.216	0.063	0.071	0.100
Actual Start	15-Jul-09	19-Sep-09	14-Oct-09	5-Nov-09
Finish	17-Nov-10	21-Oct-10	27-Sep-10	31-Jul-10
Actual Finish				
BL Project Start	28-Apr-09	19-Sep-09	14-Oct-09	1-Oct-09
BL Project Finish	10-Aug-10	21-Oct-10	27-Sep-10	10-Jun-10
Budgeted Total Cost	2245930.180	947167.290	314753.890	188255.620
Planned % Complete	0.723	0.489	0.490	0.724
Duration % Complete	0.5	0.48	0.47	0.5
Data date	40269	40269	40269	40269
Materials				
Formwork	3.161*	3.161		
Scaffolding	0.4	0.4		
Ribbed PVC	0.003	0.003		
Concrete			0.684	
Rebar				0.989
Actual hours	12665	4277	2300	1295
Budgeted hours	32013	13669	4881	2589
***Critical**				

Table 2- Critical and near critical activities considering selected material

Materials	Scenario1-critical and near critical and selected material	
	Actual quantities	**Planned quantities**
Form*	53549.184	144388.728
Concrete	1574.156	3340.633
Rebar	1280.155	2559.322

Materials	Actual	Planned	MSI
Form*	53549.184	144388.728	0.371
Concrete	1574.156	3340.633	0.471
Rebar	1280.155	2559.322	0.500
MSIt		0.447	
SPI		0.925	

Table 3- Critical and near critical activities considering all their material

Materials	Scenario 2-critical and near critical considering all their material	
	Actual quantities	Planned quantities
Form*	53549.184	144388.728
Concrete	1574.156	3340.633
Rebar	1280.155	2559.322
Scaffolding	1355.360	3654.560
Ribbed PVC	4.405	11.877

Materials	Actual	Planned	MSI
Form*	53549.184	144388.728	0.371
Concrete	1574.156	3340.633	0.471
Rebar	1280.155	2559.322	0.500
Scaffolding	1355.360	3654.560	0.371
Ribbed PVC	4.405	11.877	0.371
MSIt		0.417	
SPI		0.925	

Table 4- Critical activity considering selected material

Materials	Scenario3- critical activity and selected material	
	Actual quantities	Planned quantities
Form*	28021.756	73398.606

Materials	Actual	Planned	MSI
Form*	28021.756	73398.606	0.382
MSIt		0.382	
SPI		0.925	

Conclusion

This study introduced a newly developed Material Status Index (MSI), designed to enhance the existing earned value metrics of schedule performance. These enhancements are made possible through consideration of criticality of activities and therefore inhibiting non critical activities masking the real performance of projects. The developed MSI circumvents the problems associated with unnecessary consideration of large number of activities and therefore speeds up the process to schedule performance reporting and assists in providing insight into the root causes of schedule delays. It should be noted that these improvements are accomplished with minimal effort in terms of collecting more data from construction sites. The data required to generate MSI is already being collected in most construction projects and their related progress reports. This makes the implementation of MSI efficient, as it requires no extra effort and cost in providing the data needed for its application.

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