Material Status Index for Tracking and Progress Reporting of Construction Projects

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Abstract

Schedule performance index of earned value method has been reported to generate misleading results at times because of its failure to account for criticality of activities involved, as well as its consideration of monetary values for status reporting. Material can be seen as the fuel needed to execute projects 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 research project is geared towards circumventing the reported limitations of SPI. It presents a study on the development of material status index (MSI) in support of the EVM. Unlike the SPI, the newly developed index accounts for the criticality of project activities. The proposed method is composed of two modules: current status reporting and forecasting. The two modules include selection procedures that allow for engaging only (near) critical activities and by extension materials that impact project duration. Consideration of criticality is carried out via the total float of each activity and percent float (i.e. the ratio of float to activity duration). The MSI current status reporting and also the forecasting module utilize seventy-eight material based factors recognized to cause schedule delays. These factors were reported in a number of studies, primarily the CII 2011 publication on "Global Procurement and Materials Management" and are refined by means of a structured interview with an experienced practitioner in industry. 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 run utilizing users' judgment on the applicability of these probable causes to the project at hand in the forecasting module. The simulated model serves as input to the forecasting function, which generates probability distribution of forecasted project duration. MSI, can independently and jointly with SPI provide root causes behind problems encountered during project execution. MSI serves to provide added value in alerting management to take corrective actions. A software application is developed to automate the process of MSI method. To validate and demonstrate capabilities of the developed method, it is implemented on two case studies in which the introduced enhancements are clearly portrayed. Forecasting duration and reporting on schedule performance of project using MSI as a supplementary index is more accurate because of its consideration of level of criticality of project activities and capturing actual progress represented by quantity of material installed.

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1 CHAPTER ONE: INTRODUCTION

1.1 General

One of the main purposes of project control is to monitor project performance in order to be able to capture difficulties of the project under construction, as early as possible. According to PMBOK, determining schedule status stands first in the to-do list of project schedule controllers (Project Management Institute, 2004). The prompt diagnosis of project malfunctioning is the key to project control success. That is why a considerable portion of project control principals is dedicated to time and cost forecast. However, since construction projects don't have a static nature and predictions don't always provide the correct future performance, it is a valuable effort to ascertain the continuous performance of projects.

To ensure whether projects are proceeding as scheduled, and to plan for 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 has been the most well-known control technique presented since 1960s. However, there are some valid arguments in respect to this method that are further elaborated on, in the following section and also in the chapter dedicated to literature.

1.2 Problem statement

Many have doubted the accuracy and application of schedule performance index (SPI) of earned value method over the years. The main limitations reported are comparing project progress against a baseline that may not always be reliable (Ballard, 2008), convergence of SPI to 1 near the end of project (Lipke et al, 2009), implementation difficulties by owners (Wayne & Abba, 2009), consideration of monetary values for status reporting (Lipke, 2003), dependence on lengthy progress reports for all activities involved in the project (Vanhoucke M. , 2009). Schedule control set aside, material management is undoubtedly one of the major process groups, hard to indemnify if neglected, in any construction projects. Effective site material management practices have substantial influence on schedule performance (Thomas & Sandivo, 2000).

The aforementioned discussions, and the fact that within the whole literature an apparent negligence towards the interconnectivities of material consumption and schedule performance was observed, made this research effort to be devoted to reporting project schedule status through quantity of materials. Unlike existing schedule performance indices, this new method is capable of reporting on project status at any point of time during project execution, giving rise to recognition of schedule related performance defects as early as possible. It circumvents limitations of existing schedule performance index.

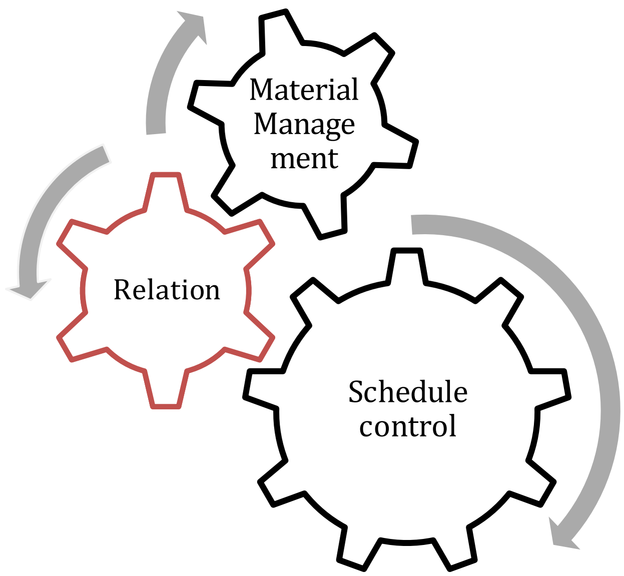


Figure 1-1- Missing correlation between material management and project control

1.3 Research scope and objectives

The main objective of this research is to study impact of material on schedule performance, which leads to introduction of enhancements to the existing earned value metrics and its schedule performance index, presenting the newly developed Material Status Index. These enhancements are made possible through:

- Considering criticality of activities and therefore inhibiting non-critical activities masking the real performance of project schedule.
- Considering the very components of progress, i.e. material quantities in calculations, rather than monetary values for all resources
- Reducing the peripheral data as of those pertaining to activities not influential to project duration at each point of time and therefore speeding up the process to schedule performance reporting.

- Providing an insight into the root cause of schedule delay.
- Extracting cited causes of schedule delay attributed to material related issues from the literature and incisively suggesting them as corrective actions, using them to aid users in the selection process and to improve forecasting accuracy

It should be noted that these improvements are accomplished with minimal effort to collect more data on construction sites, as the quantities of materials installed, which is the main character of this method, is currently being noted in many site reports. The idea behind this method is that 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 schedule performance.

Keeping archives of material related information also assists in other various instances. The documentation of day-to-day consumption of material would facilitate claim case organizations and claim settlement, therefore would help reduce conflicts. Should the state of the art technologies in tracking materials location is coupled with this method, then there would be continuous knowledge of project status.

1.4 Thesis organization

The thesis consists of six chapters. Chapter two offers a comprehensive literature review of tracking and control, schedule control techniques and material management practices. Different areas of research and extensions to the Earned Value Method (EVM) is also compared and critically discussed. Chapter three presents the proposed method, commencing with an introduction; a set of criteria, extracted from the literature is then elaborated on. The full method regarding the newly developed schedule performance status reporting and the forecasting module is presented next in chapter three. The prototype system architecture, the database and its user interface is included in chapter four. Chapter five is dedicated to case studies and validation of the proposed method. Summary, concluding remarks and recommended future work are presented in chapter six.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Schedule control methods are mainly designed to help deal with schedule overruns by early detection of potential delays and by frequent forecasting of the expected-at-completion dates making use of performance levels achieved to date as a basis for amended forecasts or other methods. In this respect, many techniques and methods have been invented by researchers, public and private organizations. EVM as a control technique that is most frequently used by practitioners and cited by researchers has gained a special interest amongst project controllers. On the other hand material management as one of the vital functions of project management has been under the spotlight of R&D (research and development) groups for long. The two fields are full of separate and scarcely at times cooperative practices and subject areas. This chapter is dedicated to delving into currently available literature in both schedule control and material management domains, as the main purpose of the study is to bridge these two bodies of project management operations. While there are numerous diverse works present in the literature, the arguments and studies presented in this chapter are exertions and achievements, most relevant to the objectives of the current research. The identified areas of available proximity in the literature, to the research project at hand are as follows:

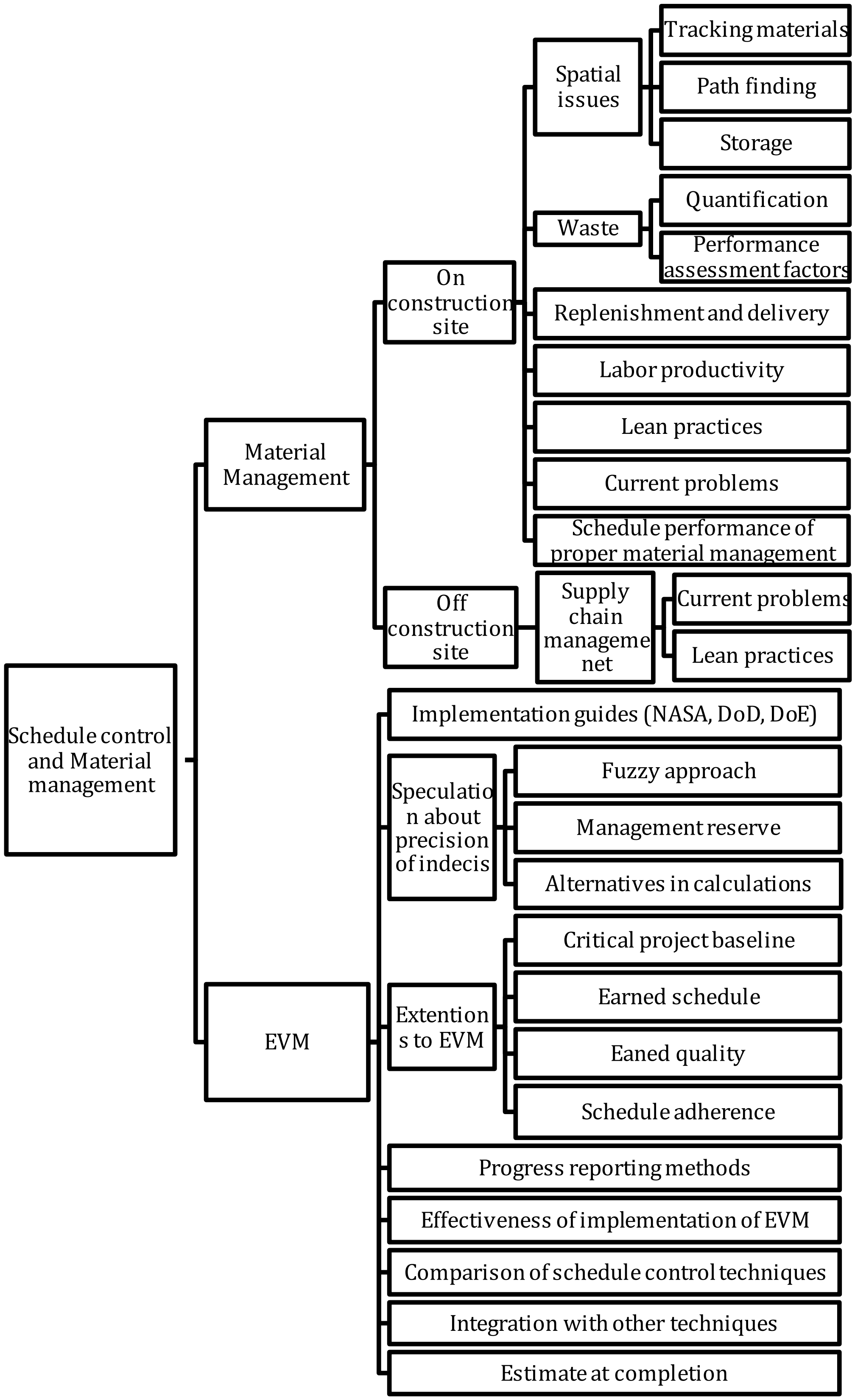


Figure 2-1- Identified literature in material and schedule management

Many researchers have doubted the accuracy and application of EVM metrics over the years. One of the fundamental criticisms of this method is that, since EVM compares the project progress to a baseline, it cannot be a suitable technique to use in highly risky projects where the amount of uncertainties hinders creation of a reliable baseline. Lean construction introduced practices that circumvent the aforementioned limitation, through the last planner method and creation of look-ahead plans (Ballard, 2008). On the other hand, some argue 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). In addition, the fact that the schedule index would hand over a result of "1" at the time of project completion regardless of project performance throughout the execution stage makes this index not applicable for an inclusive span of project lifecycle (Lipke et al, 2009). Similarly, some speculate that EVM performs well in the 20%-70% of project completion, and produces misleading results over the last 30 % of the project (Marco et al, 2009). Fleming also confirms that EVM is useful only during the early stages of the project (Fleming, 1991). Lipke proposed the new "earned schedule" concept in 2003 to overcome these shortcomings (Lipke, 2003) by calculating the schedule variance and performance index on the basis of time rather than dollar. Many fellow researchers continued to further develop this technique since 2003 (Anbari 2003; Henderson et al 2004; Vandevoorde et al 2006, 2009; Stratton 2007; Henderson 2005, 2008, Moselhi et al, 2010).

Apart from the precision weaknesses associated with the calculation of schedule performance index in EVM, the accuracy of this index is greatly dependent on the frequency of actual data acquisition from the site. Additionally, materials in this respect play the role of fuel to construction projects as the more materials get installed, the more progress the project makes. It is obvious that the ultimate aim of all project activities is to contribute to transformation of materials to a final project deliverable.

Material management practices have a great impact on schedule performance. Thomas found that schedule slippage on installation of some materials vary from 50- 129% (Thomas et al, 2005). Research developments in the field of material management are expanded through the areas of spatial issues regarding site layout through optimization of material storage on site (Tommelein 2001; Wang et al, 2005; Jang et al 2006; Hisham and El-Rayes, 2011; Huang et al, 2010), or the most economical replenishment schedule (Chen et al, 2008; Georgy and Basily, 2008); as well as, significant work on the supply chain management practices and performance measures (Love et al, 2004; Wicjramatillake et al, 2007; Pan et al, 2010; Hatmoko et al, 2010). Some focused on the waste performance (Cha et al, 2009) and quantification (Gavilan et al, 1994; Jalali, 2006; Lau et al, 2008; Soliz-Guzman, 2009; Poon et al 2009). A limited number of studies have also been done to identify site material management problems and rectification solution and practices (Thomas, 2005; Navon et al, 2006). One of the major targets of lean construction is material management, which led to many research papers and dissertations (Sacks et al, 2009; Mao et al, 2010; Kim et al, 2011).

Construction Industry Institute (CII, 2011) states as part of its best practices for material management, that: "Complete physical inventories should be conducted not only to identify deficiencies in receiving, issuing or clerical support function but also to verify location and quantity as depicted within the computerized material management system." This means, for an effective material management, quantities of materials should be known throughout the project execution. This relation has been identified since 1986. Mendel, 1986 claims there is noticeable overlap of information coverage between various parties involved in a project that if shared, could facilitate the acquisition and augment the precision of data and data analysis by different departments. The literature review proves that, this relation has been disregarded between material management and schedule control. The control department can easily attain project status by reaching out to the previously existing databases of material management team, abating the dependency of project schedule performance on site visits and percentage complete reports.

Nevertheless, the relation of material management and schedule is not left entirely unobserved. A number of researchers have delved into material delivery efficiencies and its impacts on schedule (Navon et al, 2006; Bell et al, 1986, 1987; Makulsawatudom et al, 2003; Thomas et al, 2000). They heeded to the fact that materials are among the main prerequisites of many activity fulfillments but didn't pay attention to the considerable amount of common information that's lain in between the two areas.

The reason why the implementation of EVM by project members on DoD owned projects, was impaired and required a major refinement resulting in prolix implementation practices is that the sub/contractor, supplier, etc. tended to report incorrect status of projects (Wayne et al, 2009). However, if project is procured by the DoD which is a common case in major mega projects, the selfsame entity, by the use of the proposed method in the present study, can correctly measure project progress and status, observing the objective consumption of materials.

Apart from numerous publications of the US department of defense and the US National Aeronautics and Space Administration concerning EVM which mainly focus on the implementation of the method, the developed areas within the body of project schedule control are mostly concentrated on the threshold accuracy of the indices of earned value method (Kim, 2009; Moslemi et al, 2011) or the parameters pertaining to their calculation (Moselhi, 1993; HAMILTON ALLEN BOOZ INC, 2003). Some presented other concepts like management reserved (Lipke et al, 1999), earned quality (Paquin, 1996) and earned schedule (Lipke, 2003). There's also been studies done on the performance of earned value methodology (Kim et al, 2003), and its practices (Fleminget al, 1998; Shtub, 1992)

2.2 Schedule Control

2.2.1 Controlling project schedule

Controlling performance of a project in progress is the key to its success or failure. It requires a set of metrics to determine the current progress and to forecast the future expected project behavior such that the project manager is able to timely detect project problems and take corrective actions to bring the project back on course (Vanhoucke M. , 2011). "The monitoring and control process group consists of those procedures required to track, review and regulate the progress and performance of project; identifying any areas which changes to the plan are required and initiate the corresponding changes " (Project Managemnet Institute, 2008).

PMBOK® categorizes the schedule control as one of the six main processes in time management knowledge area. Schedule control is the process of monitoring status of project and updating the progress as well as applying changes to the baseline. Baseline schedules are produced by the planning team and conventionally used as a benchmark to track performance. Functions of the control schedule consist of four main groups.

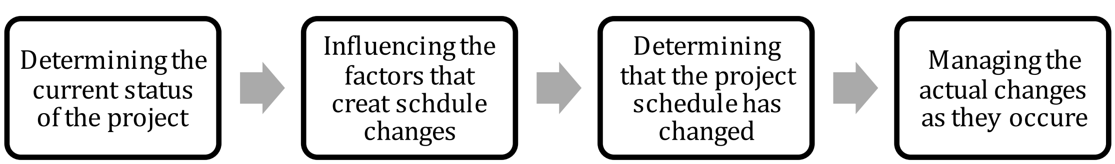


Figure 2-2- Control schedule group of functions- PMBOK® ,2008

Project control has three main components: baseline, measurement methods of progress and effective and corrective actions. (Callahan, Quanckenbush, & Rowings, 1992) (Project Managemnet Institute, 2008).

Baselines are developed based on planned schedules. Expert judgments and historical data are incorporated as well in the process of creating or choosing the most reliable baselines. Project schedules can be in the form of an early start schedule, late start schedule, baseline schedule, resource-limited schedule, target schedule or any variations of the above. (Project Management Institute (PMI), Inc., 2007).

According to the US Department of Energy publications about earned value management (Hamilton Allen Booz Inc, 2003), there are five major strategies to attain the actual progress (percentage complete) regarding earned value:

- Fixed formula determines the progress through fixed percentages assigned to start and finish of each control account. This technique is applied to work packages that span a short period of time within 3 months. It's a subjective approach and involves minimal effort to acquire. However, this technique is not effective for long-term work packages.
- Templates are suitable for activities with long-term durations. The method requires milestone assignments at each month or accounting period. Since there's an objective procedure of earned value calculation involved, it appears as a preferable approach to most project managers.

- Milestone weights: this method would not allocate any earned value to tasks until full completion of each milestones
- Milestone weights with percentage complete: where credit is also allocated to the partial completion of each task. However, it requires a "Control Account Manager" to assess the percentage complete of each milestone.
- A unit complete strategy makes use of a physical count of the units completed. The usage of this method is limited to the work packages where there are identical packages available having same budget. In other words, it's suitable for repetitive construction, like highway and high-rise buildings. In addition, this method cannot count for activities in progress either. However, it's an objective way to determine the earned value of the project.
- Subjective Percentage complete is conducted by inspectors who make regular site visits and based on the physical percentage complete of each task; they verify different activities' progress. This is a subjective approach to project progress and the accuracy of the resulted project status relies highly on the frequency of the visits.
- Level of effort is affiliated with the passage of time, meaning a predefined monthly budget is allocated to activities solely after a certain amount of time has passed. It applies mostly to activities that are more time oriented than task based like project managers' and office staff work. These work packages are highly challenged by the customers and their usage should be kept to a minimal level, since they require precise planning and assessment of performance monthly.

A corrective action is anything done to bring the expected future project schedule in line with the approved baseline. In the area of time management, corrective actions often involve expediting and root cause analysis. However, corrective actions are only taken after diagnosis of variation in planned and actual performance. What follows will elaborate on the different technics in reckoning these performance differences.

2.2.2 Performance review

According to project management body of knowledge guidebook, as one of the essential techniques of schedule control, performance review should be undertaken to measure, compare and analyze schedule performance such as actual start and finish, percentage complete and remaining duration to complete (Project Management Institute, 2004)

Earned value method (EVM) is the most widely employed technique among all the other performance measurement techniques. It is becoming so commonly used that it can be regarded as a standard in project control. More specifically, EVM brings cost and schedule variances analysis together to provide managers with a more accurate status of a project (Kim , Wells Jr., & Duffey, 2003). Even though the concept of EVM was introduced as early as late 1800, it was not until 1967 that the cost/schedule control systems criteria gained attention and were presented by the US Department of Defense (DoD). Later in 1996, the new notations of earned value method were in place by the American National Standard Institute/Electronic Industrial Association, referring to budgeted cost of work scheduled as planned value and budgeted cost of work performed as earned value (Fleming & Koppelman, 2005).

The schedule performance metrics of EVM are the schedule variance and schedule performance index. Contrary to the schedule metrics of EVM, the 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 and regardless of activity sensitivities to the end project results; all cost items are summed up in the process of generating 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). Vanhoucke et al, (Vanhoucke M. , 2008) suggested that small delays in critical activities coupled with much faster progress in non-critical activities can lead to false SPI values. Moselhi (Moselhi, 2011) suggests blacking out non-indicative periods when calculating schedule status and also focusing on critical activities rather than all activities, as non-critical ones may mask the real performance of the project.

The process of tracking and status calculations on each and every one of activities involved in the project is burdensome, especially in detailed schedules where the number of activities is abundant. Vanhoucke (Vanhoucke M. , 2009) proposes 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, Zwikael, & Anbari, 2009) also noted that a detailed schedule analysis would create heavy load and troublesome effects on the project team. Ding and Zhang, 2006 (Ding and Zhang, cited in (Chen & Zhang, 2012)), introduced another approach to resolve this problem. They proposed a parameter to measure the criticality of each activity based on the amount of float and developed a weighted SPI. Lennon and Francis (Lennon & Francis, 2010) have presented a new method to calculate SPI in a way that would mitigate its current limitations of failure to distinguish between critical and non-critical activities and also the misleading results at the end of project, which is that it always converged to 1 regardless of the performance of the project. Making use of CPM/PERT technique, they suggest recognizing the most probable activities to happen to occur on critical path at each reporting period and then providing the SPI of the project based on the identified critical activities

On the other hand, Shtub (Shtub, 1992) compared two approaches towards project control: EVM based on the work content of all activities; and CPM based on the length of activities comprising the longest sequence of tasks by means of system dynamics simulation. After simulating four factors that contribute to schedule overruns and delay, he concluded, the EVM performed better than CPM based system when initial estimates of work were inaccurate and when substantial rework was needed (two of the factors under study).

Over the years, numerous studies have been collected in academia, professional institutions and governmental departments regarding the earned value technique. DoD as the most influential founder of the EVM, has published numerous implementation guides (e.g. Earned value management system (EVMS)-Standard surveillance Instruction (SSI) (last reviewed in 2012) Earned value management systems performance, oversight and governance (2011); Defense Acquisition Guidebook: chapter 11.3.1 EVM (2009); EVM Implementation Guide (2006); Integrated master plan and integrated master schedule, preparation and use guide (2005), NASA earned value management (EVM) implementation handbook(2011); Integrated baseline review (IBR) handbook (2009)). These extensive publications were mostly geared towards preventing sub/contractors from reporting incorrect status of projects (Wayne & Abba, 2009).

Regarding the background on the earned value management, some zeroed in on the thresholds of indices and status of project and its magnitude as the index strays from the threshold. Kim et al (Kim S.-C. , 2009) argue, when the three values of EV, PV and AC are not calculated accurately, and not at regular intervals, the EV indices don't reflect the correct status of the project. Accordingly based on the historical data analysis of 20 successful (completion within planned schedule and budget) high-rise residential buildings, they denounced the judgment of project status, grounded on solely an absolute value. They plotted the SPI and CPI, and compared the different projects graphs using time series method of statistics (due to peculiarities of various projects' durations). They believe the indices shouldn't exist as absolute numbers but rather should be described as a range. Based on their findings of the historical data and best-fit analysis, they assumed autoregressive (AR) model is the fit model. They drew to a conclusion by stating the AR model was fit model for SIP but not for CPI. However, the trend line and the confidence didn't precisely represent SPI and showed low credibility whereas the situation is reversely applicable to CPI.

In addition, Moslemi et al. (Moslemi Naeni, Shadrokh, & Salehipour, 2011) argue that the percentage complete factor measured from the progress made on site is prone to subjectivity and that there shouldn't be only 1 number considered as the threshold for project deviation from baseline, which in case of CPI and SPI is 1. It is also asserted that the consideration of risk involved in project is neglected in all EVM parameters. They, therefore, suggest counting on a range as for the borderline of divergence and express the project status in accordance with the degree of applicability to the corresponding range. Using the principals of fuzzy theory and applying statistical rules, they produced new equivalents for earned value metrics.

2.3 Forecasting methods

Status reporting and forecasting come hand in hand in construction projects. As mentioned earlier, one of the main purposes of schedule control is to forecast what will happen in the future of projects, i.e. forecasting is an inevitable process in project control.

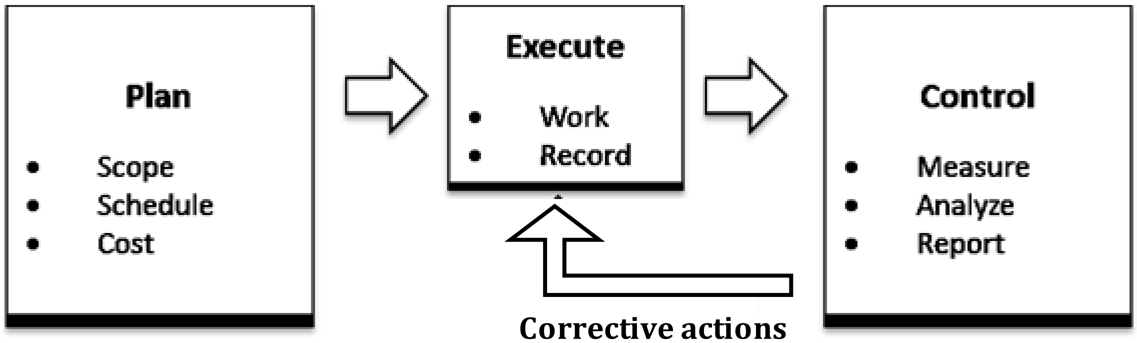


Figure 2-3- EVM and the project management process. Consideration of corrective actions adapted from PMI,2005

Figure above is originally employed from the *Practice Standard for Earned Value Management* (Project Management Institute (PMI), 2005). However, the backward arrow that links the control process group to execution can be best described as corrective actions.

Through the conventional Earned Value Management (EVM) method, there are three techniques 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).

Methods	Scenarios	Formula	Note
Planned Value	1	PD-TV	PVrate= BAC/PD TV= SV/PVrate
	2	PD/SPI	
	3	PD/SCI	
Earned Duration	1	AT+ (max(PD,AT)-ED)/(PF=1)	PF= Performance factor ED= AT*SPI
	2	AT+ (max(PD,AT)-ED)/(PF=SPI)	
	3	AT+ (max(PD,AT)-ED)/(PF= CSI)	
Earned Schedule	1	AT+ (PD-ES)/(PF=1)	
	2	AT+ (PD-ES)/(PF= SPI_t)	
	3	AT+ (PD-ES)/(PF=CSI_t)	

Table 2-1- Earned value management forecasting methods

Planned value method attempts to adjust the original duration of projects by direct use of project performance factors (cost, schedule or both). The core principle of the other two forecasting methods is the summation of elapsed time with some variations of the time still to come, corrected by a factor of past performance. These performances vary from cost, schedule or a combination of both.

There are three different approaches to forecast projects: 1-forecasting based on the original estimates, 2- forecasting based on a new estimate and 3- forecasting based on the original estimate modified by past performance information (Project Management Institute, 2004). The first two forecasting methods are valid in situations where any previous performances of the project are irrelevant to the future. Those methods require rescheduling of the whole project and revisiting the entire project history to date, which is time consuming and labor intensive. The concentration of the present research is on the third type of forecasting, to benefit from the previously experienced performance as well as experiences of project participants.

Over the years, considerable amount of studies have been conducted to improve the accuracy of these forecasting methods through deterministic or stochastic approaches. Vandevoorde et al (Vandevoorde & Vanhoucke, 2006), compared the three traditional earned value forecasting methods against a common example and found that the earned schedule method is most accurate amongst the three. However, it would be least accurate in cases when SPI (t) is incorrect. Some researchers such as Cioffi (Cioffi, 2005), focused on the accuracy of the planned schedule and its different curve variations. He examined and presented an analytical expression for the planned schedule shape under different circumstances, which are non-linear S-curves.

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. Lipke (Lipke W. , 2004), presented the effective *earned schedule concept* and incorporated the measurement of schedule adherence with earned values to measure how coherent actual execution of project is in respect to its baseline.

When project is subject to a considerable amount of rework, use of earned value method is questionable and may result in incorrect decisions. (Cooper , 2003). This is mostly due to the fact that baselines may not be updated as frequently as the reworks may take place so as to be able to capture the amount of new work added.

However many have speculated that, the fundamental principles of earned value forecasting are, 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 in a way to categorize 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 its 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 calculate time and cost at completion.

The other group of researchers, studying forecast at completion time, have presented methods to integrate EVM with other management techniques. Kim and Reinschmidt (Kim & Reinschmidt, 2010) incorporated the Kalman filter forecasting method with earned schedule method. Kalman filter is widely used in tracking and predicting complex dynamic systems such as aircraft, ships, traffic, stocks, etc. This application made it possible for the authors to develop a probabilistic prediction of duration at completion in an adaptive manner so that it can be used in the early goings of project without significantly affecting accuracy. Barraza et al. (Edward Back, Mata, & Barraza, 2004) employed the concept of stochastic s- curves and Monte Carlo simulation to determine cost and time at completion. Many researchers believe that a deterministic forecasting approach which counts for the most likely situations, and does not provide a range of possible results, should not be employed for construction projects as they have dynamically changing nature (Vergara, 1974) (Ward, 1980) (Edward Back, Mata, & Barraza, 2004) (Kim & Reinschmidt, 2010). CII (Construction Industry Institute (CII), 1987) further recommends that no single forecasting method be used; but rather to include a forecast by a number of other methods to provide a range of possibilities.

2.4 Material management

Material procurement is an integral parcel in any construction management, which has the significant impact on project productivity and cost (O'Brian , Plotnick, & , 1999). A properly implemented materials management program can influence the timely flow of materials and equipment to the job site and therefore it speeds up improved field planning, increased labor productivity and lower overall project costs (Construction Industry Institute(CII), 2011). Literature in the area of material management is vast and diverse, with subjects varying from spatial storage optimization and site layout to delivery schedules, different best practices, waste, supply chain management, performance indicators, etc.

2.4.1 Problems on construction sites

In the scope of material management problems, Navon et al. (Navon & Berkovich, 2006) conducted a survey to find what the existing problems at construction site level are, regarding material management. They identified problem areas regarding material management difficulties on site. A set of 4 algorithms was developed by them to suggest solutions to overcome the predicaments they recognized. Their model was implemented on MS Access software. To test the validity of their proposition, the writers carried out an on-site experiment and concluded that their model helped increase availability of materials on site resulting in higher productivity, provided more accurate and up-to-date information about the materials, decreased surplus and waste, and facilitated the tracking of planned and actual consumption of materials especially for the purpose of further flawlessly planning of future projects. One of the great contributions of their research was that they were able to compile a practical and imperial study and survey that best illustrates what the main day-to-day issues of material management is in construction sites. Within the same context, Thomas et al. (Thomas & Riley, 2005) divided the construction site to 3 areas: exterior, staging area and interior storage. Based on a case study, they proposed material management practices regarding each zone in an effort to reduce likelihood of cost and time over run. Construction Industry institute, through its publication of the best practices on global procurement and materials management, 2011, discusses a series of procedure, strategies and necessary operations for different project members to follow to be able to more efficiently handle material related issues from its production in manufacturing units to its installation on construction site, this reference source is particularly helpful in guiding material managers in how different complications can arise in construction projects regarding their material practices.

2.4.2 Material management performance

Some believe that small companies have no or very deficient material management systems. Bandyohpadhyay et al. (Bandyohpadhyay, 2002) did a survey among 34 contractors from results of which the writer created a set of procurement practices and common procedures to help small companies brush up on their previous policies of procurement and material management. On the other hand, Mendel

(Mendel, 1986) argues that there should be integration between project control and material management. Four key contributing elements to this integration are: organizational structure, project reporting, system integration and historical information. He then further discusses how important the aforementioned parameters are. Mendel strongly emphasized that there is considerable overlap of information coverage between various parties involved in the project that if shared, could facilitate the acquisition and augment the precision of data and data analysis in different process groups.

2.4.3 Site layout

A considerable portion of the literature on material management has been dedicated to optimizing storage areas or spatial site layouts (Said, 2010) (Ma, Shen, & Zhang, 2004) (Jang, 2006) as few examples of different subtopics. Said found the optimum site layout (with respect to optimum storage occupation) at each replenishment period which has the minimum logistics cost with the help of genetic algorithm. What they deemed the logistics cost to be consisted of are: ordering cost (material and delivery cost), layout cost (handling cost, resource travel cost and site reorganization cost), financing costs (the possible gain of the owner's tied up material purchases stored on site, over transformation of those assets into working capital) and stock-out costs (how much the project will suffer financially from material unavailability). They implemented their methodology on an actual construction site to evaluate its potency, which confirmed the expected results of their methodology that there are interconnections between material procurement and site space availability as well as the interdependencies of site layout decision and material storage needs. (Ma, Shen, & Zhang, 2004) took a 4D approach to site layouts, giving a 3d site layout visualization at different points of the project life; while Wang (Wang & al, 2005) presents the optimum site layout through optimizing the cost of three entailing factors: material flow factor, shape ratio factor and area utilization factor. The genetic algorithm was employed to generate the desirable results in their study.

2.4.4 Lean construction

2.4.4.1 Lean practices

Originating from lean practices in manufacturing industry, lean construction is gaining a significant amount of attention amongst both researchers and practitioners. With materials getting introduced as one of the preconditions for any construction task (Koskela, 2009); many studies in the field of material management have been centered on this topic. As a response to the last planner practice of lean construction and in an effort to reduce inventory on site, Kim et al (Kim & et al., 2011) developed a material management system that is based on the daily production schedule. Their proposed methodology consists of the following steps: retrieval of master schedule, creating the 4week look-ahead schedule, task schedule formation, daily task meeting, allocation of daily progress payment, identifying the required materials for the daily tasks. They implemented all stages on a computer program that is fed by the user, project activity schedule and material requirements of each task. They validated their model by applying it to a real world construction project. Concentrating on the transparency practices of lean construction and the fact that construction sites are always very dispersed and have dynamic physical environments, Sacks et al. (Sacks, Treckmann, & Rozenfeld, 2009) integrated BIM with a series of developed user interfaces to help the work team find and project managers identify the status of each activity on site in order to direct work teams to the areas where activities are in progress. On the other hand, Hongtao et al. (Hongtoo, 2010) developed a model that promotes the lean practice of transparency of operations within construction site. Their main focus was to create transparency of material availability through a shipment tracking approach; and to shorten the response time in the supply chain by exerting a proactive delivery strategy. By dint of keeping apprised of incoming shipments and outgoing materials for installation from the warehouse, while knowing the material requirements of each task, the last planners will be able to put forward the accomplishable tasks with the existing materials; and reschedule the rest to a later date when the material requirements are satisfied. Consequently if the upcoming material needs are directed straight to the supplier, similar to Vendor Managed Inventory, the problem of long response time is solved, via giving the responsibility of the delivery of goods to suppliers.

2.4.4.2 Waste

Research in the area of waste management covers mainly topics in elimination of waste and environmental provisions, and quantification of waste. Waste elimination is a process that avoids, eliminates or decreases amount of waste at its source or allows for reuse/ recycling of the waste for environmentally friendly purposes. (Guthrie & Mallett, 1995). Cha et al. (Cha, Kim, & Han, 2009)'s research resulted from a comprehensive literature review in which they produced 59 influencing factors to help decrease waste on construction sites. Based on these factors, they created a questionnaire that was answered by fifty seven experts. Results of the survey were fed into an assessment tool designed by the writers as databases to help support their system. They claim that by means of their developed system, project managers are aided to more efficiently assess their project performance in terms of waste management. Masoudi et al (Masoudi, 2011) did a comprehensive literature review on waste quantification regarding only buildings. Their studied methods are the ones suggested by:

- Gavilan & Bernold (Gavilan & Bernold, 1994), Bossink & Brounwers (Bossink & Brounwers, 1996) who were the pioneers of waste quantification, state that 1-10% of ordered material ends up as waste. They believed waste is generated during: design, procurement, handling, operation and as residual.
- Poon et al. (Poon, Yu, & Ng, 2001) (Poon C. C., Yu, Wong, & Cheung, 2004) (Jaillon, Poon, & Chiang, 2009) suggest to calculate waste generation based on the Gross Floor Area (GFA). They introduced the waste index as total volume of waste generated over GFA. Based on the waste per GFA they demonstrate that waste is in the range of 0.125 - 0.25 m^3 (waste index). However, this index depends on the type of building, technology used for construction and size of project.
- Jalali (Jalali, 2007) introduced the two "global index "and "component index", meaning that the waste quantity is expressed either on multiple individual material basis with different units or as a single inclusive index of whole project scilicet, as the summary of all component indices.
- Lau et al. (Lau, Whyte, & Law, 2008) studied housing projects in Malaysia. They categorized the generated waste as stockpile, gathered, scattered and stacked. The

resulted values of waste had a unit of tones per hectare of site. They demonstrated that the timber makes up the most of construction waste, followed by concrete.

- Soliz-Guzman (Solis-Guzman, Marrero, Montes-Delgado, & Ramirez-de-Arellano, 2009) suggested a similar index to waste index.
- UK building research establishment (Building research establishment, 1981) developed an online tool for waste quantification, which carries out results once the user provides it with environmental and key performance indicators of a specific site.

2.4.5 Supply chain management (SCM)

Love et al. (Love, Irani, & Edwards, 2004), believe that the construction industry has a poor uptake of the supply chain management. They find that a holistic approach is the most suitable to construction SCM. They argue that integration, coordination and planning during detailed design phase to a greater extent are the keys to a seamless supply chain management. Writers provide a series of suggestions and practices for project facilitators (project managers) based on surveys with experts in the domain. On a similar research topic, Wincjramatillake et al. (Wicjramatillaka, Koh, & Arunachalam, 2007) pointed out what the areas of concerns are in supply chain management of large scale projects and measured the performance of the production and supply chain; Observing, interviewing, and investigating job diaries of luggage handling project of €6bn London Heathrow terminal 5 construction. The materials existing in the supply chain were categorized into in-house productions, resale materials and third party supplied items. The identified concerns were: performance measurement needs of the items in supply chain, items not owned by the supplier, lack of detailed planning causing changes to baseline, intricate WBS causing complications to analysis, organizational structures, Inaccuracies of data entries, timing of the cost and progress capturing, scope and change traceability. Using RFID and PDA technologies, Wang et al. (Wang, Lin, & Lin , 2007) developed a system for the supply chain of construction industry from the point of fabrication of the material to its installation on site. Their model considered eight steps for each and every element flowing in the chain: production, test, storage, delivery, onsite, inventory, inspection and installation. Their proposed model will give project members the ability of keeping abreast of the material status at each point of time. It is an online prototype, which further facilitates members' access to the supply chain related information and status updates.

2.4.6 Inventory systems

Material inventory systems are used by practitioners to help them in making a decision on when and how much material is demanded by projects (Said, 2010). The objective of employing these systems is optimize the cost associated with purchasing, transportation and storage of materials, while satisfying the quantities required at each point of time by the project.

There are two inventory systems: demand–push and demand-pull. Demand push system is an inventory system control where procurement orders are scheduled in advance based on estimates of demand and supply rates; examples of this system include fixed-order-quantity, fixed-order-period, period patch control, materials requirements planning and manufacturing resource planning. Demand-pull system is a method, reactive to current inventory level and site requirements meaning that replenishment quantities and timings are triggered by real construction activities, examples of which include, reorder point system and just-in-time.

Table 2-2: Material inventory systems (Said, 2010)

Attribute	Demand-Push Systems	Demand Pull Systems
Description	Replenishment system is triggered by interpretation of the expected demand and scheduling of supply to meet that demand	Replenishment system is triggered by the usage or depletion of stock
Objective	Minimize Cost	Minimize inventory and waste
Complexity	High	Low
Methodology	Resource allocation	Representativeness
Types	• Fixed order quantity system • Fixed order period system • Period batch control • Materials requirements planning (MRP1) • Manufacturing resource planning (MRP2)	• Reorder point (ROP) system • Just-in-time (JIT)

Many researchers have attempted to create models to optimize procurement quantity and schedules. As such, the objective of Chen et al.'s (Chen et al. 2008) research was to find optimum site layout at each replenishment period which has the minimum logistics cost. By optimizing the quantity and frequency of each material replenishment schedule, based on the least cost and least storage space required, they developed their model. Looking at the historical market price change, they simulated the best-cost plan for procuring steel bars to obtain what the best timing and quantity of purchase can be. The simulation is implemented on MATLAB environment. They claim the same process can be carried for other materials in construction site.

Through studying a real case, Thomas et al (Thomas et al. 2009) simulated the process of delivering, handling and installing the precast concrete façade components of a building. To accomplish this, they employed 3 delivery strategies (JIT, JIT+JIC and traditional temporary storage on site) to understand which one best suits the operation at hand. They concluded that the JIT approaches proved to outperform in terms of the time and cost, since there's a double handling of specimen involved in the other two cases studied. However, between the two JIT deliveries, the JIT+JIC was preferred over the just-in-time method of replenishment due to necessity omission of lingering the truck sojourn at the construction site for unloading purposes.

2.5 Summary

Different research studies on schedule control and material management were examined. In the area of material management, studies and best practices mainly focus on spatial issues, waste, replenishment schedules and problems encountered on construction sites and beyond throughout the entire supply chain; while schedule control being one of the essential components of control process groups and more specifically EVM as its prominent technique, it has been primarily investigated to produce cons and pros of implementing EVM, introduce extensions to existing EVM metrics, incorporating its practices with new techniques and generating estimate at completion.

Failure to account for criticality of activities, dependence on the lengthy progress report of *all* activities involved in the project for calculations and monetary notion of progress achieve are the main limitations reported in the literature. Consideration of all dollar values of all resources is not reliable as it is not a good measure of physical progress achieved on site.

Activities are the major control points amid the conventional project control methods. To determine progress of projects, the physical completion of each activity is estimated by the use of methods mentioned earlier. The process of collecting percentage complete of activities, reporting them to the office and projecting the obtained data on the project baseline is a time consuming, labor-intensive job. Even with the current advancements in the area of site data acquisition and the breakthrough IT management systems; there's the inevitable need of data analysis after their collection; for the information to be useful to project managers and reporters. Alternatively, project progress can be directly evaluated through quantities of materials consumed to contribute to project accomplishments. If the physical progress of project is deemed to indicate project advancement then the quantity of materials, actually used to execute the work, is what the physical progress consists of.

Apart from Mendel's obscure notion of benefits hidden in integrating and sharing information between different functions of construction management groups, current studies have not yet addressed this issue. Even though, researchers have advanced copiously in the locals of material management influences on productivity and subsequently schedule performance, the benefits in *directly* making use of quantities of materials installations on site and material installation performances in schedule control has been left out.

3 CHAPTER THREE: Developed Method

3.1 Introduction

Material Status Index (MSI) is a newly developed index, aimed to augment existing SPI metric of EVM. It measures the schedule performance of project using quantities of material in place, which are 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 quantities of materials consumed to contribute to project accomplishments.

3.2 Causal factors

One of the main objectives of the method presented is to determine what the root cause of project schedule delay is. Doing so requires engagement of all different possible causes of delay on project schedule. As this research project is aimed to study impact of material management on schedule performance, the delay causes conducted are directly associated with material related issues.

In this respect, a comprehensive literature review was carried out to find what material related drawbacks could possibly occur to delay project. 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
- On site- after acceptance.

Fifty items among the list of these causal factors are extracted from the CII best practices on global procurement and material management, forty-seven of which have been found to be restated in literature. There are also fifty-three factors from fifteen different journal and conference papers in the list of causal factors.

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. Some of the causal factors are specific to a particular type of material. For instance the causal factors associated with manufacturing are only applicable to engineered materials and is not pertinent to bulk or manufactured types of materials.

These causal factors are used to compliment the proposed methods on three fronts.

- To act as checklist for the user to select materials to consider for calculation.
- To suggest them in form of applicable corrective actions as part of the current status reporting process
- To have the user select from them, the applicable causes of delay projected from the report day till the targeted time horizon

The three practices are more elaborated on, in their respective section within the current chapter.

3.2.1 Extractions of factors

The extracted causal factors are obtained from a wide range of reports, papers and publications of various institutions and researchers. They are categorized on the basis of different locations where the difficulties may arise, the various functions involved at different stages of material management and their conventional sequences during project execution. These factors are summarized in the following tables.

3.2.1.1 Supply chain

The supply chain category encompasses all the activities and functions required to provide construction sites with materials. Since there are numerous parties involved during the supply chain and before materials reach the site, the number of causal factors recognized in this category is comparatively greater than the other two categories. Different causal factors within the different functions at different stages of supply chain are tabulated below, with the notion of applicability of each causal factor to each type of material.

Table 3-1- Causal factors during supply chain

<table>
<tr><th>Area</th><th>Sub Area</th><th>Issues</th><th>Column1</th><th>Source</th><th>Year</th><th>Type</th></tr>
<tr><td rowspan="6">Supply chain</td><td rowspan="6">Manufacturing</td><td rowspan="3">RFI (Request For Information)</td><td>Failure to timely issue an RFI</td><td rowspan="3">Subsomboon</td><td rowspan="3">2004</td><td>E</td></tr>
<tr><td>RFI Failure to pursue correct contractual standing orders</td><td>E</td></tr>
<tr><td>A/E failure to timely respond</td><td>E</td></tr>
<tr><td rowspan="3">Shop drawing and approval</td><td>GC/subcontractor failure to timely develop shop drawings</td><td rowspan="3">Subsomboon</td><td rowspan="3">2004</td><td>E</td></tr>
<tr><td>A/E failure to approve shop drawings</td><td>E</td></tr>
<tr><td>Failure to timely fabricate</td><td>E</td></tr>
</table>

Area	Sub Area	Issues	Column1	Source	Year	Type
			materials			
	Purchasing	MTO (Material Take-Off)	Inaccurate takeoff quantities	Subsomboon	2004	MEB
				CII	2011	
					1999	
		RFQ (Request for quotation)	Failure to issue an RFQ	Subsomboon	2004	MEB
			Failure to timely respond to RFQ			MEB
		Purchase order	Order quantity misunderstanding	Navon et al	2005	MEB
			Order specification misunderstanding	Navon et al	2005	MEB
			Order delivery time misunderstanding	Navon et al	2005	MEB
			Failure to order before lead time	Navon et al	2005	MEB
				CII	2011	
			Unnecessary reordering	CII	2011	MEB
		Acquisition difficulties due to political issues/foreign issues		CII	2011	MEB
	Expediting	Status reporting & Level 1	Lack of information regarding order status	Navon et al	2011	MEB
				CII	2011	
				Soekiman	2011	
				Wang et al	2007	
		Level 2	Unavailability of detailed order schedule	CII	2011	E
			Unavailability of historical performance of suppliers	CII	2011	E
				Kerridge et al	1986	
			Supplier unwillingness to cooperate	CII	2011	E
			Expediting difficulties due to second and third tier suppliers	CII	2011	E
		Lack of experienced personnel		CII	2011	ME

Area	Sub Area	Issues	Column1	Source	Year	Type
						B
		Material expediting not coordinated with the erection sequence		Thomas et al	1989	M E B
	Inspection	Quality assurance	Lack of adequate systems to deliver quality product	CII	2011	E
			Lack of ISO certification of suppliers' QMS	CII	2011	E
		Quality control	Failure to be validated as required specification	CII	2011	E
			Ascertaining difficulties regarding materials' origins	CII	2011	M E B
			Non recognition of counterfeit items	CII	2011	M E B
		Insufficient quality requirements (materials, processes and personnel) from owner or designer		CII	2011	M E B
	Transportation	Contractual issues		CII	2011	M E B
		Insurance related issues		CII	2011	E
		Freight issues	Incorrect cost estimates	CII	2011	M E B
			Tariff related issues	CII	2011	E
			Selection of unsuitable freight line	CII	2011	E
			Inaccurate routing guide	CII	2011	M E B
			Packing problems	CII	2011	M E
			Inexperienced freight forwarders, marine surveyors and export pacers	CII	2011	E
			Surface handling problems	CII	2011	E
		Security issues		CII	2011	M E B
		Government rules		CII	2011	M E B
		Lack of suitable infrastructure		Navon et al	2005	M

Area	Sub Area	Issues	Column1	Source	Year	Type
				CII	2011	EB
				Mawdesley et al	2002	
				Parsons et al	1980	
E: Engineered M: Manufactured B: Bulk						

3.2.1.2 At the gate before acceptance

The causal factors related to receiving area before granting admission to enter the site are tabulated below. Many of the factors in this category are concerned with the fact that materials may not comply with what is expected of each delivery package as planned. Every so often, materials get rejected depending on the specific conditions of projects or state of deliveries.

Table 3-2- Causal factors at the gate before acceptance

		Sub Area	Issues	Source	Year	Type
Receiving Area	Noncompliance of delivered materials to plan	Time	Early delivery of materials	Navon et al	2005	MEB
			Late delivery of materials	Navon et al	2005	MEB
				CII	2011	
				Soekiman	2011	
				Thomas et al	1989	
		Cost	Noncompliance of deliveries with planned cost	CII	2011	MEB
		Specification	Mismatch of delivery specifications with plan	Navon et al	2005	MEB
				CII	2011	
				Thomas et al	1989	
		Quantity	Less than planned quantity delivery	Navon et al	2005	MEB
				CII	2011	
			More than planned quantity delivery	Navon et al	2005	MEB
				CII	2011	
	Deficient signage and directional signs			CII	2011	MEB
	Untargeted deliveries			Navon et al	2005	MEB

		Sub Area	Issues	Source	Year	Type
	Erroneous delivery registry			Navon et al	2005	MEB
	Unsafe deliveries			CII	2011	ME

3.2.1.3 On- site after acceptance

Once accepted to enter the site, materials are either stored to be used later or are immediately consumed. Nevertheless different issues can occur at this stage, which may affect schedule. It should be noted that, the level of applicability or intensity of each of these causal factors is in direct relation with the degree of site congestion and site-specific conditions.

Table 3-3-Causal factors on-site after acceptance

Area	Sub Area	Issue		Source	Year	Type
On site	Storage	Unavailability of right equipment		Navon et al	2005	MEB
		Unavailability of right crew		Navon et al	2005	MEB
		Storing materials in temporary craft storage areas, shacks, gang boxes and staging areas instead of storage areas		CII	2011	MEB
		Materials improperly sorted or marked		Thomas et al	1989	MEB
		Site laydown areas	Insufficient knowledge of on-site stock	Navon et al	2005	MEB
			Inability to determine material locations	CII	2011	MEB
				Subsomboon et al	2003	
				Parsons et al	1980	
				Echeverry et al	1997	
				Nasir	2008	
			Insufficient storage area due to site congestion	Navon et al	2005	MEB
				Said et al	2011	
				Parsons et al	1980	
			Insufficient provisions	CII	2011	ME

Area	Sub Area	Issue		Source	Year	Type
			for laying materials			B
		Warehouse	Lack of warehousing facilities	CII	2011	MEB
				Parsons et al	1980	
			Insufficient knowledge of quantities	CII	2011	MEB
			Problems with warehouse requisition obtentions	CII	2011	MEB
			Lack of security and access control	CII	2011	MEB
	Handling	Insufficient rigging requirements		Navon et al	2005	MEB
				Parsons et al	1980	
		Inexperienced workforce		CII	2011	MEB
				Navon et al	2005	
		Extensive multiple handling of materials		Thomas et al	1989	MEB
					2005	
				Ng et al	2009	
		Trash or debris obscuring access to materials		Thomas et al	1989	MEB
	Waste	Deterioration		CII	2011	MEB
		Theft		Navon et al	2005	MEB
				CII	2011	
		Loss		Navon et al	2005	MEB
		Inaccurate quantification of change orders				
		Natural catastrophes		CII	2011	MEB
	Installation	Unavailability of right equipment		Navon et al	2005	MEB
				Parsons et al	1980	
		None supply of manifest or erection documents by supplier		CII	2011	E
		Unavailability of right crew		Navon et al	2005	MEB
		Inexperienced workers		CII	2011	MEB

Area	Sub Area	Issue	Source	Year	Type
		Crew slowdown in anticipation of material shortage	Thomas et al	1989	MEB
	Others	Material possession conflicts between subcontractors	CII	2011	MB
		Material related paperwork	CII	2011	MEB
			Parsons et al	1980	
		Remobilization and refamiliarization after a lengthy delay	O'Connor	1968	MEB
			Subsomboon	2004	

3.2.2 Refinement of causal factors

In order to have a much more reliable set of causal factors to either suggest as corrective actions during current status reporting or employ to adjust the individual MSIs' future performances, a round of refinement of these factors originally extracted from the literature, was carried out. These refinements were made possible during a structured interview with an expert with over twenty years of experience in the domain of material and procurement management of mega construction projects. The interview was structured in a way for the interviewee to respond to a set of 78 questions. These questions were initiated from the 78-itemized list of probable causes of schedule delay due to materials, extracted from the literature. The respondent was asked to fill out the questionnaire forms in two separate rounds:

There were two of the same booklets to be filled in two separate rounds:

- First round: To verify whether the factors cited are applicable in general and respondent would agree to consider them to cause delays. This step is geared towards refining the existing set of causal factors.

- Second round: To verify whether the factors sited are applicable to the respondent's specific discipline of profession and that he/she would agree to consider them to cause delays. This step is geared towards creating a domain specific set of causal factors.

To verify the answers, the respondent was to choose from one of the following options:

- Accept: He/she would agree to consider the factor to cause delays
- Delete: He/she would not agree to consider the factor to cause delays
- Merge with: Factor seems to be redundant and could be joint with another factor

The general questionnaire was also filled by two industry practitioners with more than 10 year of experience in construction management. Results of the interview and survey reveals that nearly 80 % of the causal factors cited in the literature were found to be applicable to the domain of chemical and petrochemical. It was also discovered that approximately 85% of the causal factors were found applicable to all projects in general. In three of the 78 questions asked, the respondent was hesitant about the applicability of the factors and therefore, refrained from making comments. None of the causal factors were found redundant and repetitive. Likewise, there were no additional factors added to the list of probable causes of schedule delay due to material. The answers are tabulate in the following table.

Table 3-4- Refinement statistics suggested

Questionnaire Type	Additions	Deletion	Merge (Redundancy)	No Answer
General	0	11	1	3
Domain Specific (chemical and petrochemical)	0	13	2	3

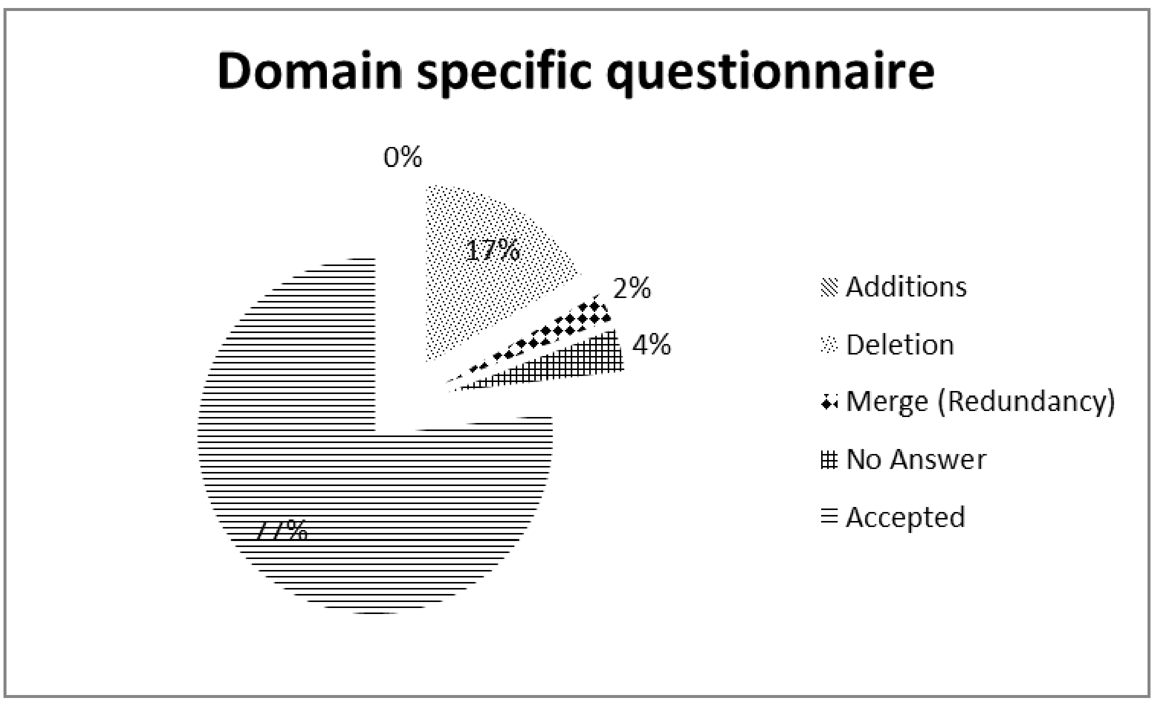


Figure 3-1- Responses received on the domain specific questionnaire

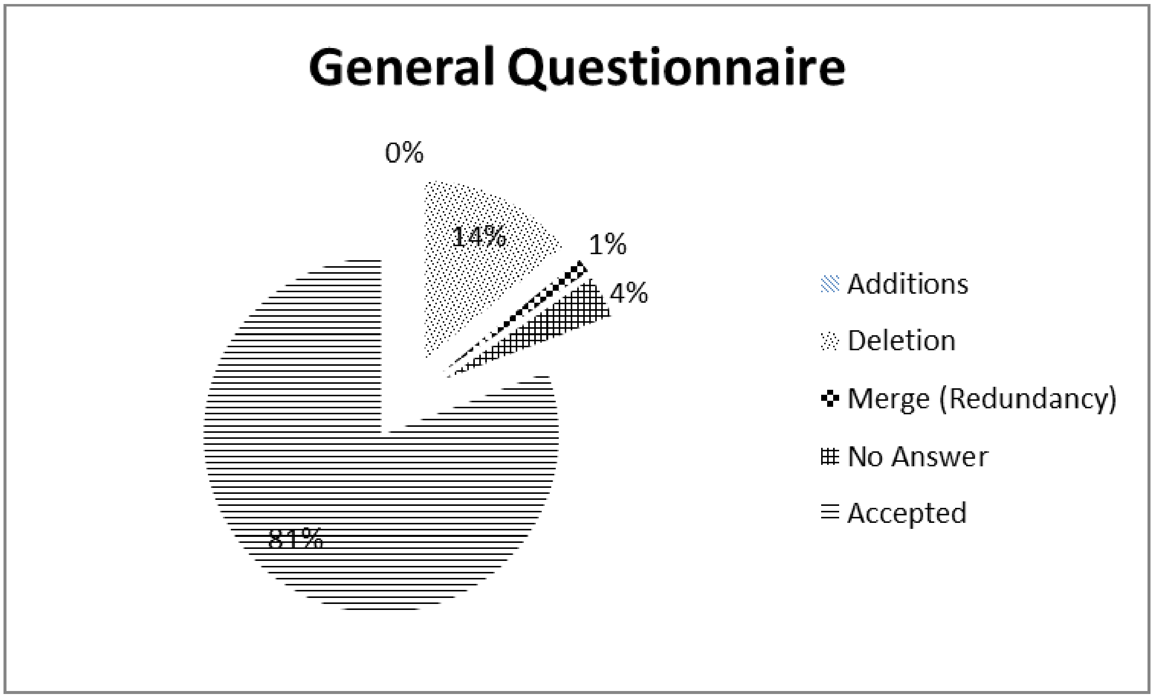


Figure 3-2- Responses received on the general questionnaire

The modifications suggested in the both sets of questionnaire include:

Table 3-5- modifications suggested in both questionnaires

Area	Sub Area		Causal factor	Suggested modification	Questionnaire type
Supply chain	Purchasing	Purchase order	Order quantity misunderstanding	Deletion	General and domain specific
			Order delivery time misunderstanding	Deletion	General and domain specific
	Inspection	Quality Assurance	Lack of adequate systems to deliver quality products	Deletion	Domain specific

Area	Sub Area		Causal factor	Suggested modification	Questionnaire type
		Quality control	Failure to be validated as required specification	Deletion	General and domain specific
			Ascertaining difficulties regarding materials' original	Deletion	General
			Non recognition of counterfeit items	Merge	Domain specific
	Transportation	Freight issues	Incorrect cost estimates	Deletion	General and domain specific
			Incorrect routing guide	No answer	General and domain specific
		Other	Insurance related issues	No answer	General and domain specific
Receiving area	Noncompliance of deliveries with plan	Time	Early delivery of materials	Deletion	General and domain specific
			Late delivery of materials	Merge	General and domain specific
		Quantity	More than planned quantities delivered	Deletion	General and domain specific
	Others	Unsafe deliveries		No answer	General and domain specific
On- site	Storage	Warehouse		Deletion	Domain specific
	Handling	Insufficient rigging requirements		Deletion	General and domain specific

Area	Sub Area	Causal factor	Suggested modification	Questionnaire type
		Trash or debris obscuring access to materials	Deletion	General and domain specific
	Waste	Natural catastrophes	Deletion	General and domain specific
	Installation	Unavailability of right equipment	Deletion	Domain specific

The rest of causal factors not stated in the table above were accepted.

3.3 Material Status Index (MSI)

3.3.1 Current status reporting

To attain continues schedule status of project through material consumption, close monitoring of material quantities is required, as the accuracy of EVM indexes is greatly dependent on the frequency of actual data acquisition from the site. Integrating the state of the art technologies in tracking materials on site with the MSI method allows for generation of continues schedule status of project via measuring the ratio of the actual quantities installed to planned quantities that should have been installed till the respective report date.

One of the principle focuses of this study is to account for the criticalities of activities involved in project. That's why a procedure is pursued to select the impacting activities and eventually materials. On the other hand materials are the control points considered by the MSI, as opposed to activities in Schedule Performance Index (SPI) of EVM. Materials possess different units and cannot be all indexed directly in one function. 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 below depicts the procedure taken in calculating the MSI.

In obtaining the conventional SPI, calculations are on activity levels. However, in the MSI method, control points are materials. The material status index follows the same actual vs. planned principle of EVM performance indices, but with a further laser focus, down to the components of activity progress, i.e. materials in place.

The process in calculating the MSI is illustrated in the following figure. It should be

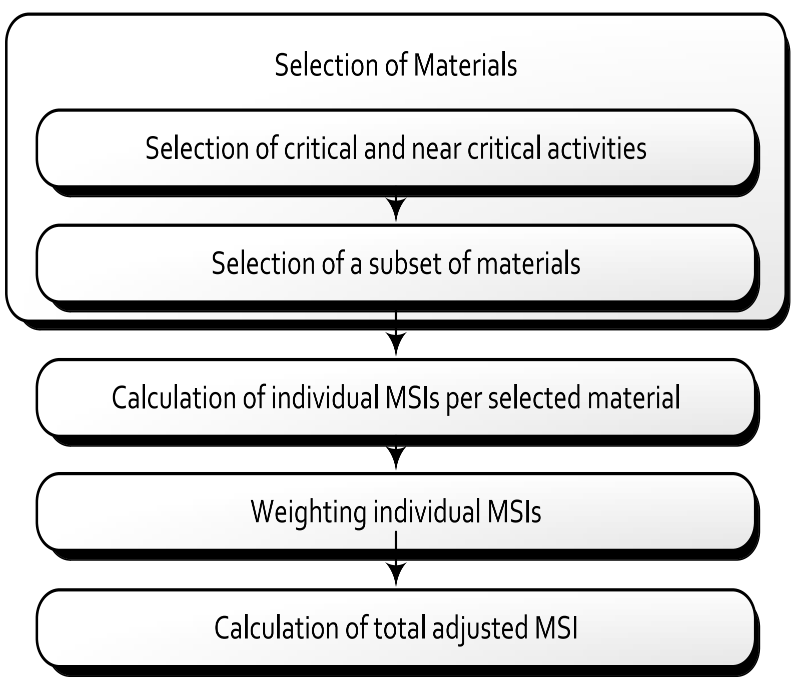


Figure 3.3- Overview of the process in current status reporting

noted that, the complete process should be carried out, each time MSI is reported during the execution of project as not only materials used by activities at each point of time constantly change that is new materials get introduced and sometimes while others may disappear from the enlisted materials for construction, but new activities and materials become critical at different points of time depending on project conditions.

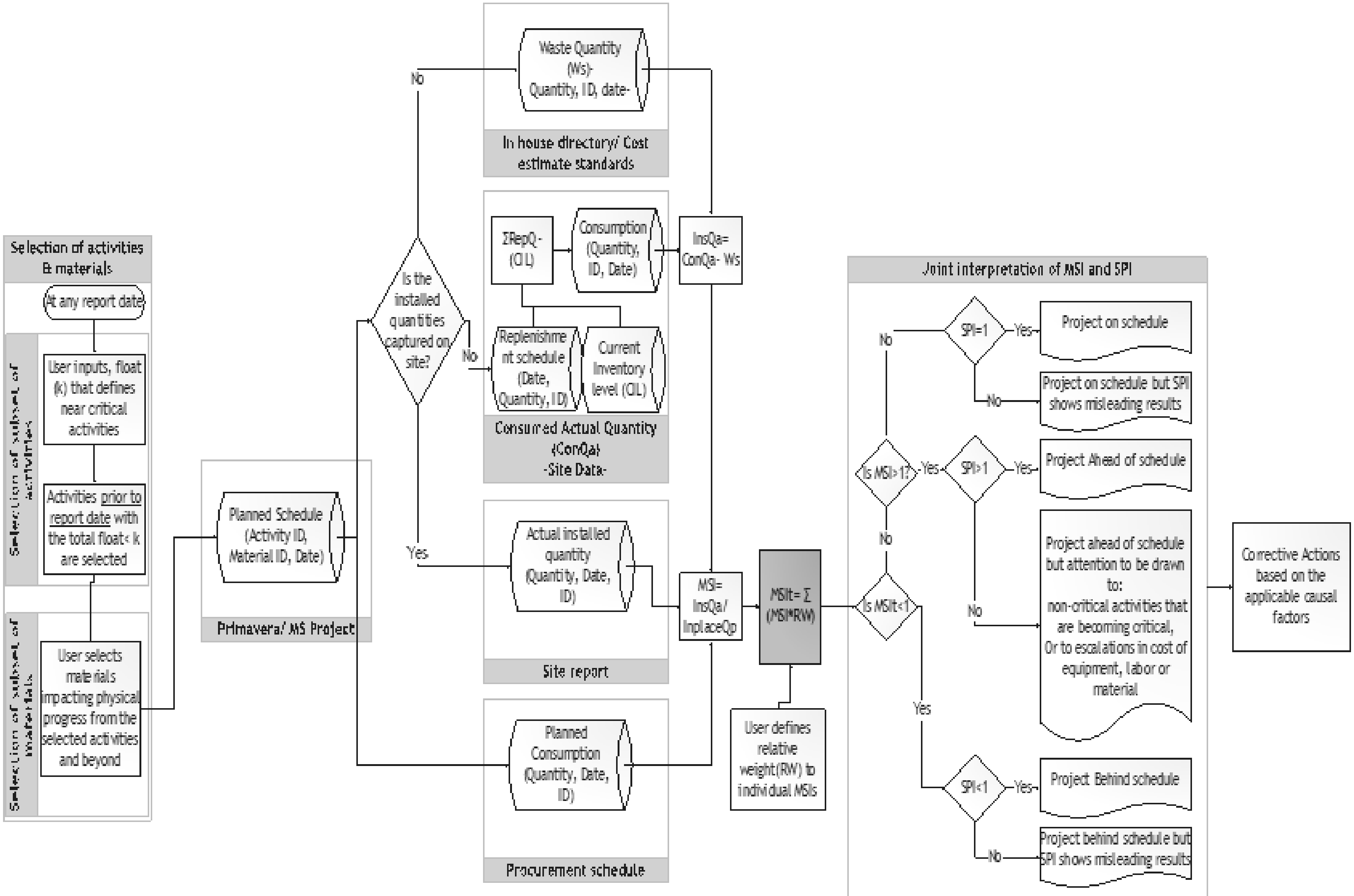


Figure 3-4- Current status reporting module

3.3.1.1 Selection of materials

In the proposed method, materials in place are indicative of a set of activities that consume those particular materials. Thus, criticality of materials is implicit in 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: It is obvious 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 (material) is in direct relation with its total float.
- Total float to duration ratio: However, total float per se is not fully capable of providing a good measure of criticality. Imagine two activities with the same total float but different durations. Chances are higher for the activity (material) with the longer duration to get delayed under normal identical circumstances.

In selecting materials for MSI calculation, both conditions are evaluated to ascertain whether or not to include a material in MSI process. This process reduces the number of involved activities (materials) to a great extent and right before further endeavor is carried out, reduces the amount of unnecessary data acquisition and calculation. The primary objective of this process is to avoid status of non-critical activities, which would not affect the duration of project, mask the real performance of project. This sifting procedure also allows for a much more manageable set of control points to concentrate on while not compromising inclusion of vital-to-the-performance details of the project, as achieved in the calculations of the performance indicators using higher WBS levels.

At times, near critical activities (materials) are also influential on the project duration for which there should be a mechanism in place that specifies which activities should and should not be included in calculations. Since construction projects are of dynamic nature and schedules are designed in a way to accommodate the 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. However, through the case study, the industry partner suggested a value of 15% of project duration to be set for default calculations. Nevertheless, user who is the most knowledgeable person of the project at hand 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.

This threshold determines the first subset of materials. However, some project dependent factors can become a determinant of project schedule performance at times, which the user should be able to pick from the bill of material and create another round of further filtering of materials to be undertaken to form the most indicative materials of the schedule performance.

Nonetheless, if the project manager finds use of all materials in the project helpful towards project schedule performance, This step can be skipped and have the criticality of materials affect each individual material status index (MSI) ‘s weight when calculating the total MSI for the project.

3.3.1.2 IndividualMSI

Material status index is a material driven indicator, which would deliver efficiency of material installation in terms of time. All the activities consuming the same material are clustered together to be represented by an individual MSI for that specific material. The ratio of summation of actual material quantities 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.

$$\textbf{Material Status Index per material m}: \mathbf{MSI_m} = \frac{\sum_{i=1}^{n} \mathbf{InsQa}}{\sum_{i=1}^{n} \mathbf{InsQp}} \qquad \textbf{(3-1)}$$

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

It should be noted that, in the process of collecting the total actual quantities of materials consumed (installed); it cannot be 100% determined whether the quantities consumed were to contribute to the progress of (near) critical activities or non-critical ones. That is to say that the final subset of materials selected to be considered towards MSI calculations is inclusive of the quantities of materials that could potentially be consumed by non-critical activities as well. This will translate into an accuracy limitation with projects whose activities are designed in a way that more than one activity consumes a specific material.

To attain continuous reporting of project schedule status through material consumption, close monitoring of material quantities is required. The following sections will elaborate more on how the quantities are obtained for the MSI calculations.

3.3.1.2.1 Planned quantities

The planned installed quantity is determined from an integrated schedule of material takeoff and project schedule; that is, the gradual installation of materials through project execution, derived from project blueprints. If a project is benefiting a BIM model, the installation schedule is automatically generated from the 4D model. This is a straightforward process that does not require any updates and can even be done once in the life time of a project, in case there is no change to the baseline. However, if there are additions made to a project scope, as the project execution proceeds those additions and deletions (mainly perceived as change order) associated with quantities of materials should be recalculated and revisited. Such update of planned schedules ensures that the project maintains a reliable baseline and consequently accurate performance indices.

3.3.1.2.2 Actual quantities

Tracking actual installed quantities is a more challenging task to fulfill. Materials are brought to site on a timely basis, according to the replenishment schedule set by the material manager. Traditionally, superintendents manually took note of the time, quantity, and quality of the delivered packages. It was an error prone process that seized a lot of time from both site personnel and transporter. However with the current advancements in the domain of automation in construction, the application of RFID quickly propagated especially through material related endeavors and paved the way for accurate, near real time compilation of data without human intervention.

The net consumption of materials by project is the total replenished quantities minus quantities remained, residing in the storage areas (warehouse or site yard). 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, incidents on site, change orders, reworks, etc.

A significant amount of 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 (Legislative 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.

$$InsQ_a = ConQ_a - W \qquad \textbf{(3-2)}$$

Where InsQa is the actual installed quantity; ConQa is the actual consumed quantity; and W is the waste quantity.

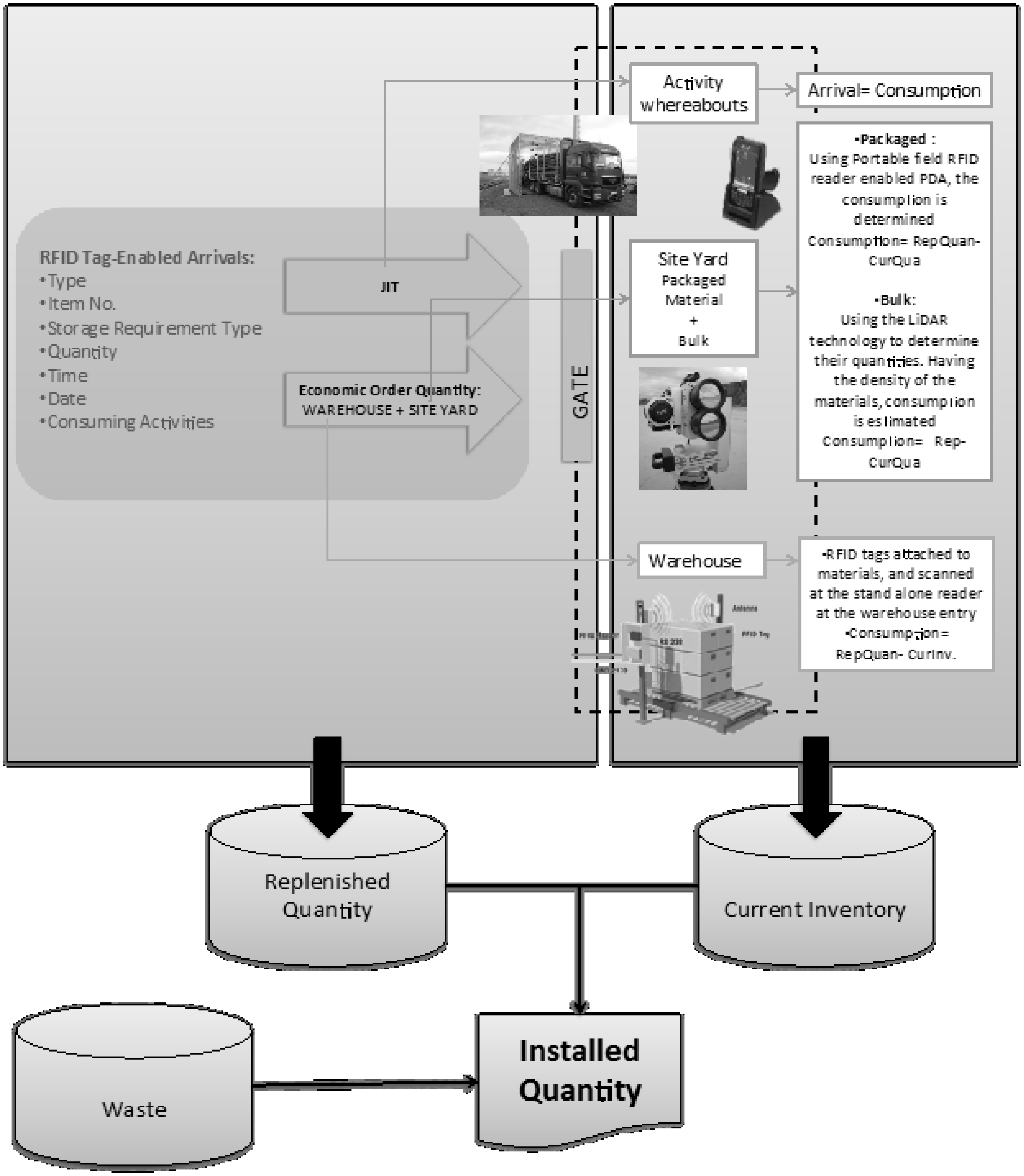


Figure 3-5- Tracking actual quantities on site

3.3.1.3 Weighting

To obtain a total material status index for the whole project, rather than for a number of activities, which consume a common material, a relative weight is assigned to each individual MSI. Criticality can be defined in different ways:

- Float score: total float and its ratio to the duration of each activity that is further attributed to materials and individual MSIs.
- User judgments: based on the seventy-eight list of casual factors to potentially delay project
- Activity weights: set by the user based on the special practices of the company, available templates or historical data

3.3.1.3.1 Float score

To evaluate criticality of activities based on their total floats, the largest total float of project is identified initially. The detected value is assigned as the maximum score. Each material's criticality is determined via the criticality of its consuming activities. Therefore, subsequently, the activities within the same material are individually granted a float score. The activity float score is the difference between the maximum score and respective activity total float.

Float score of activity i: $FSi = Max_f - F_i$ **(3-3)**

Where Max_f is the detected maximum total float; and Fi is the total float of activity i.

The total float score of each material is calculated via the summation of float score of the respective activities:

Float score of material m: $FS_m = \sum_{i=1}^{k}(FS_i)/k$ (3-4)

Where FS_m is the float score of each material; and FS_i is the float score of activity i.

Float score of each material is determined as the mean value of a float score of each of its consuming activities.

For those activities that happen to have the same total float and therefore the same float score, the total float- duration ratio is the determinant of level of criticality; the greater this ratio, the less critical the activity becomes, as it implies that it possesses a shorter duration.

Total float-duration ratio= F_i / D_i **(3-5)**

Where D_i is the duration of activity i.

Just like the float score, float-duration score is calculated based on the difference between the maximum value found among all the selected project activities as their float-duration and the total float-duration ratio of respective activity.

Float-duration score of activity i: $FDS_i = Max_{fd} - F_i / D_i$ **(3-6)**

Where Max_{fd} is the detected maximum float-duration ratio among all project activities. Float-duration score of each material is determined as the mean value of float-duration score of each of its consuming activities.

To obtain weight of each material, an average value of two ratios is considered: float score of material to the summation of float score of all materials and the total float duration ratio of material to the summation of total float-duration ratio of all materials.

Material weight: $$\boldsymbol{MW_m} = \frac{\left[\frac{\mathbf{FS_m}}{\sum_{\mathbf{m=1}}^{\mathbf{n}}(\mathbf{FS_m})}\right] + \left[\frac{\mathbf{FDS_m}}{\sum_{\mathbf{m=1}}^{\mathbf{n}}(\mathbf{FDS_m})}\right]}{\mathbf{2}} \quad (3\text{-}7)$$

Where MW_m is the weight of material m; FS_m is the float score of material m and FDS_m is the float-duration score of material m.

The valid argument with employing the user judgments to define weights for each materials and individual MSIs, is the inevitable subjectiveness that is along with it. However, the list of seventy-eight causal factors is suggested to be consulted as a checklist that provides a shared insight towards the probable factors that may affect material criticality. Such treatment would mitigate the subjectivity of criticality decisions made by different users.

3.3.1.4 Total MSI

Total MSI indicates the overall schedule performance of project as opposed to material specific index that the individual MSI represents. Materials for the use of MSI calculations are a critical subset of all materials in project. Thereby, allocation of an equal weight to each individual MSI is a reasonable treatment towards the initially selected set of materials assumed, and their consolidation into one index. However, more detailed weighting procedures, as proposed in its appropriate section, leads to a more accurate performance reporting.

$$\mathbf{MSI_t} = \sum_{\mathbf{m=1}}^{\mathbf{n}} (\boldsymbol{MW_m} * \mathbf{MSI_m}) \quad (3\text{-}8)$$

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

3.3.1.5 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 varying values. However, the added value in utilizing MSI lies in those cases where MSI and SPI have discrepancies and therefore MSI can point at the root causes of schedule slippage. The following six scenarios can occur regarding MSI and SPI.

MSI>1 and SPI>1:	Project is ahead of schedule
MSI<1 and SPI<1:	Project is behind schedule
MSI=1 and SPI=1:	Project is on schedule
MSI>1 and SPI≤1:	Project ahead of schedule but attention should be drawn to non-critical activities that are becoming critical
	Attention should be drawn to escalation in cost of resources
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
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

3.3.1.6 Corrective actions

Corrective actions are suggested to different conditions and material requirements of projects, making use of the compiled set of causal factors. These factors are evaluated to figure if they are pertinent to the three different types of materials: bulk materials, manufactured materials or engineered materials. That is, material type among other fields function as attributes of every material on the project's bill of material. These attributes are discussed in details in chapter four and the section dedicated to database design. Hence, depending on which materials are deemed towards calculations of MSI, corrective actions are suggested in respect to the type of considered materials.

3.3.2 Forecasting module

A good forecasting technique is one that contains both the historical trend-based data and the competent of judgments based on construction experience and knowledge (Al-Tabtabai, Hashem; Diekmann, James E.;, 1992). To date, no methods satisfactorily addressed the issue of objective user judgments 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.

The forecasting works fairly similar to the current reporting module of the proposed method. That is, the selection, individual MSI calculation and MSI total are also parts of the process for forecasting. However, the followings are the variations that can be recognized in the two modules:

- Materials selected are those, whose associated individual MSIs are deemed to perform differently beyond the reporting date, from what seen of them to date,
- The selected materials are adjusted in a way to account for uncertainties predicted by the user to be associated with the future of those materials
- These probable uncertainties can be found among the list of causal factors extracted from the literature
- The adjusted/ non-adjusted individual MSIs are merged into one index to form the total adjusted MSI, which is used in the forecasting formula.

The main idea of using the causal factors in forecasting is to provide a checklist for the users to remind them of the probable causes of material related delays on site. Since specific conditions of each construction site are unique, providing a limited number of causes is unrealistic. Thus, the person in charge of project control should be able to point out from the exhaustive, suggested list what they see fit to their project.

3.3.2.1.1 Selection of MSIs for adjustment

The method starts with selection of materials and individual MSIs that are deemed to perform differently from what has been observed of them to date. In light of the fact that this method is intended to create flexibility in order to account for different project specific needs and conditions, the role of user judgment in incorporating those unique project conditions into the proposed method is crucial. However, user is aided in this process by the list of causal factors. This list acts as a checklist to the novices and as a reminder to the professionals in considering all the potential circumstances associated with the future of materials for drawing to better decisions.

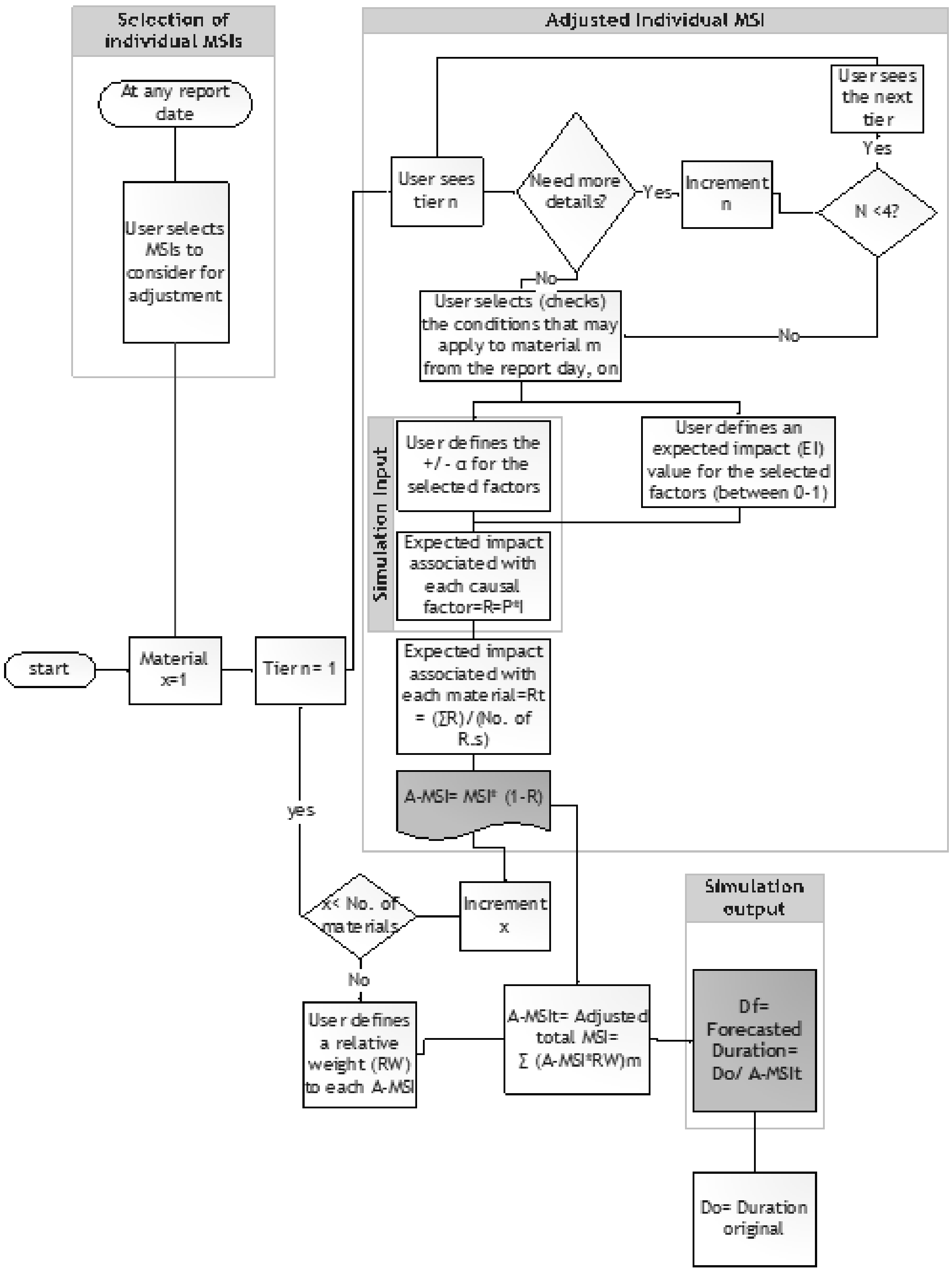


Figure 3-6- Forecasting module

3.3.2.1.2 Adjustment of individual MSIs

Each individual material status index is then adjusted so as to account for uncertainties. The user, from the list of 78 causal factors, is intended to be able to identify these uncertainties. The expected impact of each identified causal factor per selected material is next assigned within a predefined range, from 0-1. 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 inputs 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 carried out as indicated in the following equation.

$$\mathbf{A - MSI_m = MSI_m * (1 - R_m)} \qquad \textbf{(3-9)}$$

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 in the activities consuming the respective material, whereas a positive value indicates improvement over the cumulative performance achieved up to this reporting period.

3.3.2.1.3 Adjusted total MSI

To obtain a total material status index for the whole project, rather than for a number of activities that consume a common type of material, a weighted average should be deployed. The weights applied to each (adjusted) individual MSI, is obtained from the weighting procedure described in the current status reporting section.

$$\mathbf{A - MSI_t = \sum_{m=1}^{n} (A - MSI_m * W_m)} \tag{3-10}$$

Where A-MSI$_t$ is the adjusted total MSI for material m and W_m is the relative weight of material m.

3.3.2.1.4 Forecasted duration

Duration at completion or at 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 (by adjusting the MSI total).

$$\mathbf{Forecasted\ Duration = D_F = \frac{D_o}{A - MSI_t}} \tag{3-11}$$

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

3.4 Limitations

Even though this study rectifies the misleading results that the SPI produces at time and can successfully enhance the existing performance indicator of EVM, there are some limitations associated with its applications and accuracy. These constrains are as follows:

- The proposed MSI metric is only applicable to the execution stage of construction project lifecycle as it involves quantities of materials installed on site.
- The accuracy of this index is dependent on the domination of material installation among the rest of defined activities in the project
- This method cannot be applied to projects where the number of level of effort activities is relatively more significant than the material driven ones.
- The prerequisite for the effective enforcement of this method is contingent upon a robust material management system in which quantities replenished, stored, wasted and residuals are meticulously tracked and noted in a shared repository

3.5 Summary

This study introduced a newly developed Material Status Index (MSI), designed to enhance the existing earned value metrics of schedule performance. It measures project performance based on the quantities of materials rather than monetary values, as is the case with SPI. The 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 currently being collected in most construction projects and their related progress reports. This makes the implementation of MSI efficient, as it requires minimal extra effort and cost in providing the data needed for its application. The extension introduced to MSI is in enhancing forecasted project duration. A newly developed forecasting method was also presented to improve and supplement the existing earned value forecasting formulas. These enhancements are set forth through the consideration of activity criticality and uncertainty in forecasting. The use of set of causal factors is expected to reduce the subjectivity associated with direct adjustment of calculated MSIs.

4 CHAPTER FOUR: PROTOTYPE SYSTEM DEVELOPMENT

4.1 Introduction

The present chapter is dedicated to the developed prototype system for the MSI. The main purpose of automating the process to obtain the developed MSI index is to facilitate its application and reduce the effort needed to manually carry out the necessary steps and calculations. The embedded list of causal factors within the prototype evokes the probable causes of schedule delays due to material for the use of experienced practitioners. On the other hand, it is beneficial to the novices in the field by means of imparting the exhaustive list of causal factors to them. This application proves particularly advantageous in the selection steps of the proposed method when filtering and tapering the activities and materials to be considered. This automation allows for swift implementation of the first step and incorporating the user inputs into the method.

This prototype is windows-based software and is coded in the Visual Studio integrated development environment using C# programing language. It is a standalone application that can be run on various versions of the Windows® operating system. SQL is employed as the database programing language Even though, tables and relations between them are defined in the database, the ORM (object relational mapping) framework has been used to create and map database objects in C# windows application, in order to minimize the computational efforts in the database and expedite the process of creating the meaningful links between the user inputs and records nested in the database.

System architecture

There are three main components that interact with the developed software: database, graphical user interface and the @Risk software. The user has access to four elements of the developed user interface: 1) current status reporting, 2) list of causal factors 3) forecasting module and 4) forecasting report. Flexibility as one of the main features of the method is well demonstrated in the developed software through the many crucial interactions, the software is designed to have with the user. In light of the fact that construction projects are of exceptionally dynamic and idiosyncratic nature, the developed software is targeted to create a convenient platform for the user to integrate his/her insights of the project with the proposed calculations based on the developed sequence of actions.

The main two input providers for the software are the user and reports from the project jobsite. What interacts directly with the user is the Graphical User Interface (GUI) whereas the data obtained from project reports are stored in the database. The coded software serves as the intermediary between the database on one hand, where the project data is stored, and the user input on the other hand, where the specific insights of the project can be solicited from, with the logics, expressions and statements of the software based on the developed MSI method. Using the available data and the logics of the application (based on the MSI method) outputs are generated.

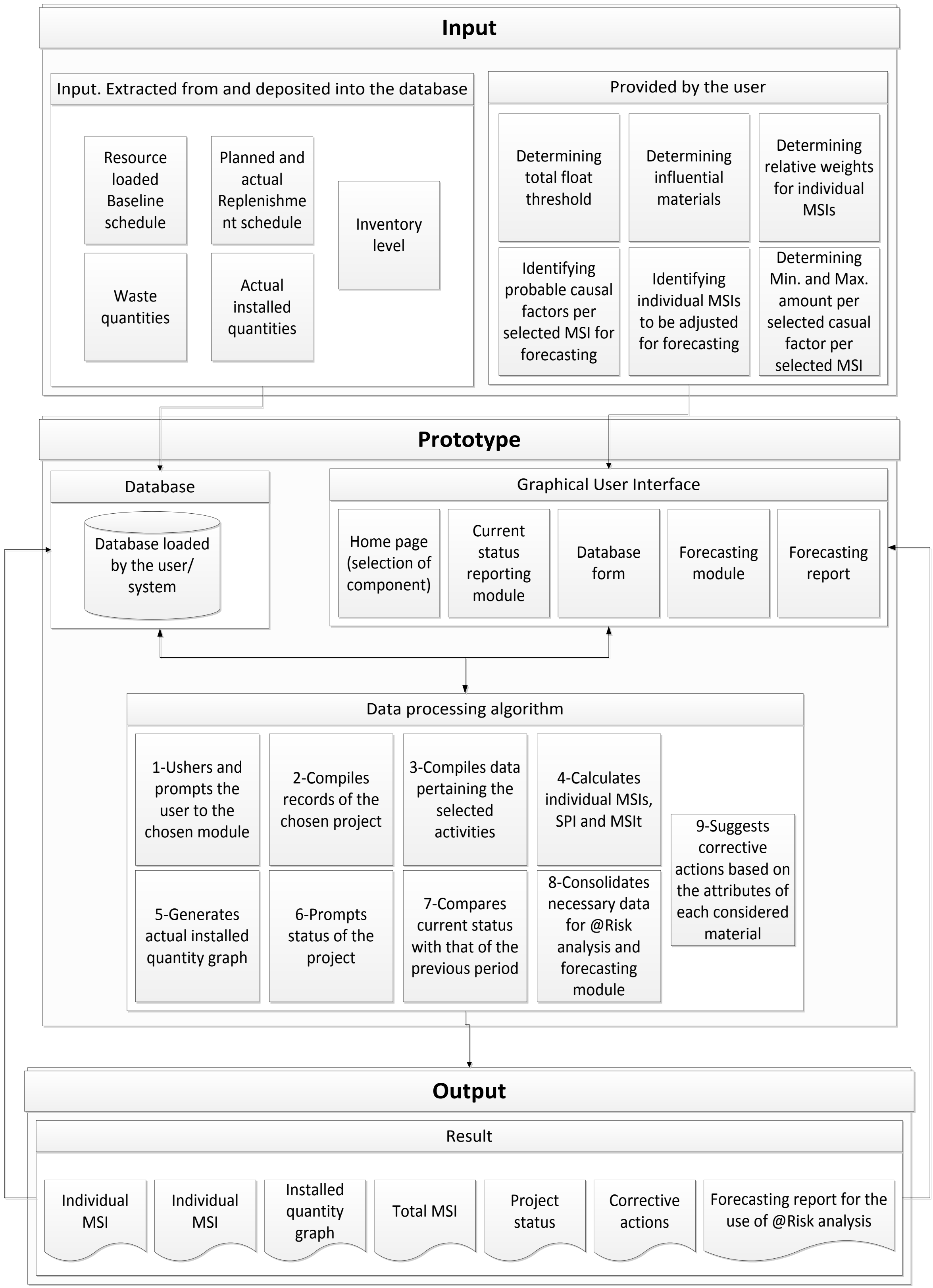


Figure 4-1- Software architecture

4.2 Graphical user interface

The window forms are developed in C# programing language. In designing the interactive screens, user friendliness and self-guidance as well as considerations to respect the goals of MSI method were granted highest priorities. There are a total number of seven windows developed to act as the medium for the user to communicate with either the system or the database. Given that the method is composed of two main components and that the application is designed flexible to loading the database right from the GUI, a homepage is designed to prompt the user to the desired component.

The first option on the home screen menu impels the user to the current status-reporting component of the method. This component is further elaborated in three tab windows. Each tab represents each step required to take place in obtaining the total project material status index, which is representative of the project schedule performance. This process is commenced by selecting the project, activities and materials to focus on. This window allows user to:

- Select from the projects loaded in database.
- Select the period of time, for which he/she wishes to get the total MSI for.
- Specify the total float criticality threshold. If the user decides to consider only critical activities, activities with total float of 0 or less appear in the designated list box.

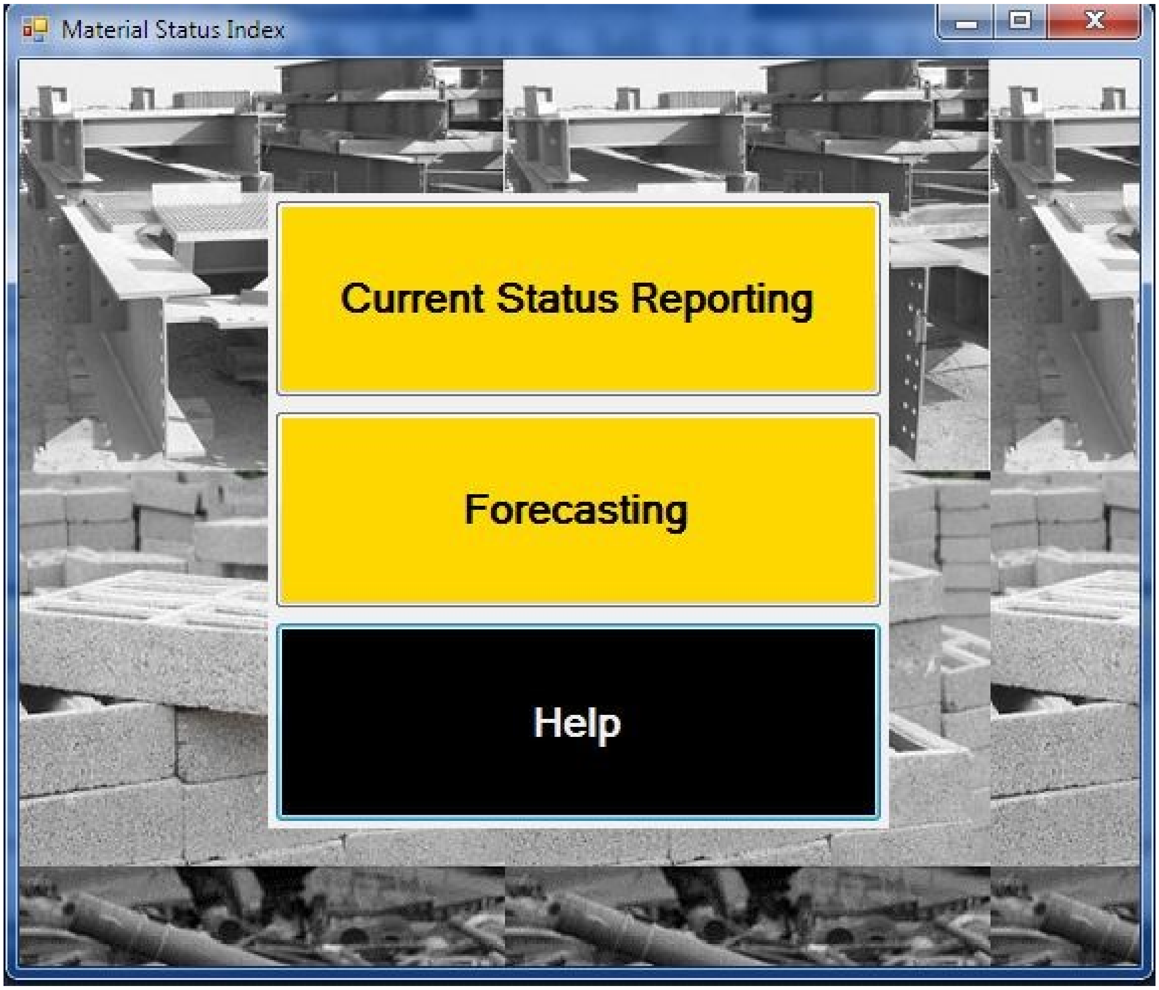


Figure 4-2-Application home page

- And select the influential materials from the list of generated and screened materials. In this process the system compares user inputs with their respective records on file and the software enables the user to pass through the first stage of the method, selection of materials. User has the ability to view materials for the selected (near) critical activities and also the full list of materials extracted from the bill of material.
- Consult the seventy- eight list of causal factors so that user can make a more educated selection of materials to consider. This list acts as a checklist to remind the user of the probable causes of schedule delay directly related to material.

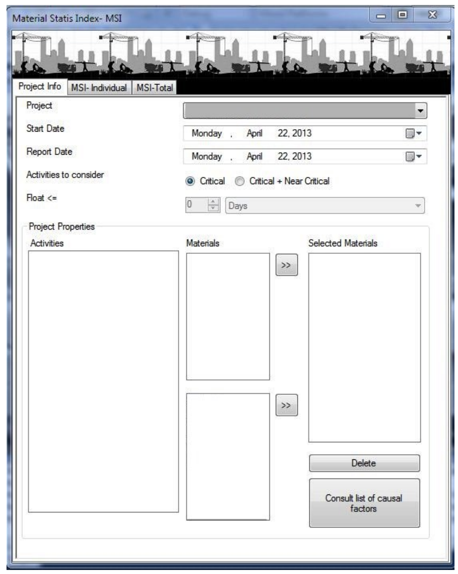


Figure 4-3- Current status reporting-Project info tab

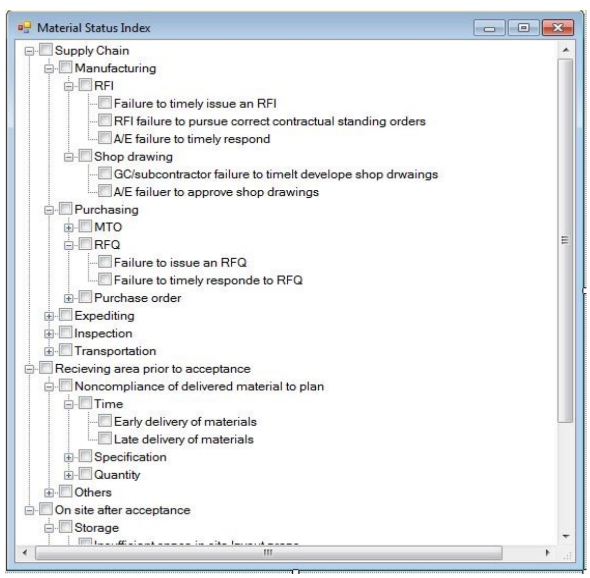


Figure 4.4- List of causal factors

The second step is to calculate individual MSIs per selected materials from the previous window. The previously selected materials are listed in a dropdown menu, from which the user should select one at a time and repeat the process for all the enlisted materials. Upon selecting each material, the data pertaining to that specific material is prompted from the database and displayed in the designated spaces. The data screened at this point from the database is specific to each material. The data include material kind, waste percentage, planned and actual quantities. Since there are many different methods of acquiring actual data on site, depending on the method, respective actual quantity information is prompted. The only other input the user is required to provide on this page is the relative weight of each individual MSI if he/she wishes to use custom weights.

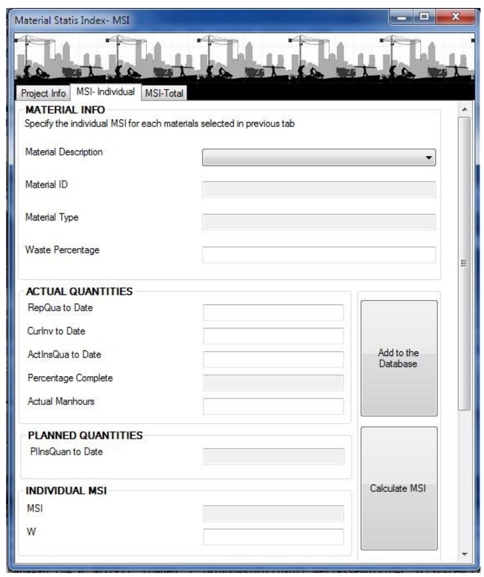


Figure 4-5- Current Status reporting- Individual MSI page

After all the individual MSIs are calculated and their respective weights have been input by the user, the MSI_t which is the total MSI can be delivered in the third tab of current status reporting page. However, to better grasp the real performance of the project, the MSI_t of previous period is also perceptible in this page. Apart from MSI_t, SPI at the current and previous period is calculated. Based on the SPI and MSI_t, the project status, currently and observed in the last period is prompted is their respective text boxes. The recommended corrective actions are based on the status of individual MSIs that present less than desirable schedule performance. Recommendations are given to each group of activities consuming each material represented by one individual MSI contingent upon applicability of causal factors to the type of materials.

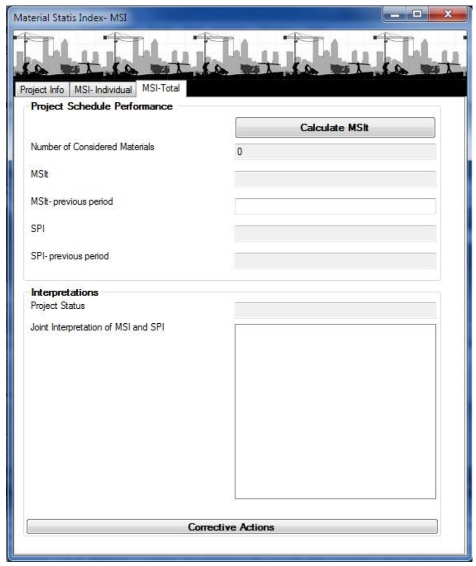


Figure 4-6- Current status reporting-MSIt, Joint interpretation and corrective actions page

The forecasting module of the developed method in the prototype consists of a two-tab page. The first page is dedicated to soliciting information from the user to choose those individual MSIs to be adjusted for the use of forecasting formula. The individual MSIs calculated in the previous module should be shortlisted by the user by selecting them from the dropdown menu.

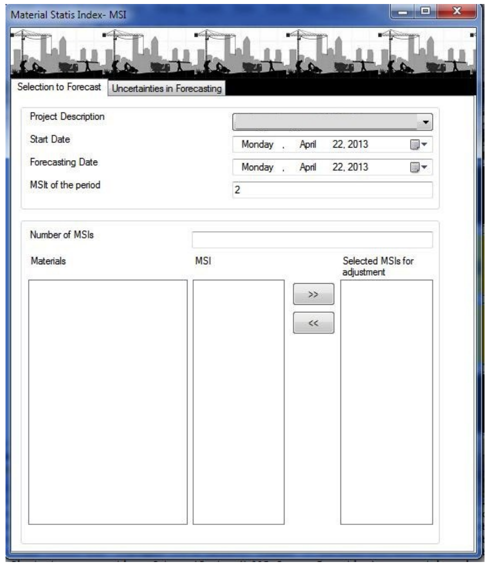


Figure 4-7- Selection for forecasting

The second tab of forecasting module is designed for the user to define applicable causal factors to each selected individual MSIs for adjustment. The user selects each MSI from the drop-down menu, then identifies from the collapsible tree menu where the 78 causal factors are nested, those causes that may delay the project beyond the reporting date on. Next, a minimum and maximum value per selected causal factor per selected MSI should be determined to act as the input for the symmetrical triangle density function (employed as the default probability function). These data get stored in the database and are ready for export to @Risk software where the simulation model is created and user-defined number of iterations materializes to provide the user with probabilistic project duration. The graph of different project durations against their respective probability percentage is delivered based on different iterations made possible by the Monte Carlo simulation.

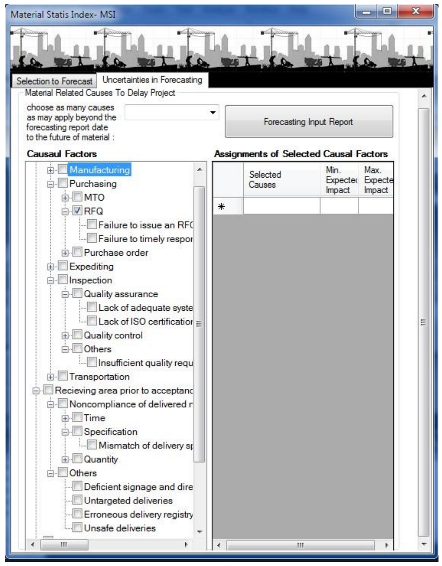


Figure 4-8- Forecasting simulation and @Risk Input

@Risk

Once in @Risk environment, the Minimum and Maximum value pertaining to each identified causal factor per individual MSI (those selected for adjustment) are assigned as the Min and Max values of the triangle density function. The most likely value for the function, depending on the desirable optimism scale of the user, can be any values between Min and Max. In this study, no skewness towards a specific value is considered by default; that is, the mean of the two set values is deemed as the most likely scenario. These distribution functions act as the input to the simulation model. The function, in which the inputs should be plugged in, is then run on the inputs and a probabilistic model to represent the duration of project is delivered. Upon defining distributions, the mean distribution models of each set of causal factors per MSI are handed over. These probabilistic means obtained from evaluation of casual factors are used to adjust each MSI. Next, the forecasting function is applied and a probabilistic duration of the project is forecasted.

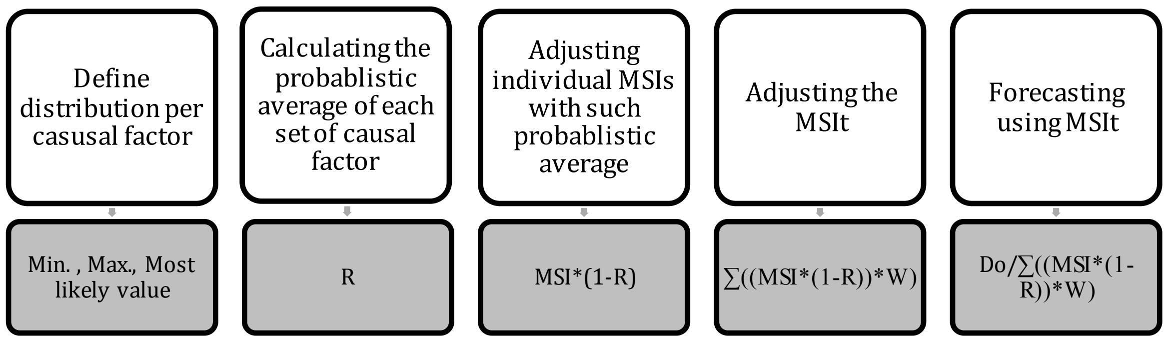


Figure 4-9- Forecasting module calculation sequence

4.3 Database

Database is the repository where the project data is stored. The records are categorized and housed in their respective tables. The programing language employed for the database is SQL. Tables and relation of each table to the other are defined in the database. However, queries for the use of the system are coded in C#. There are a total of 14 tables in the database. Some of the tables like activities and materials have a many to may relation with the WBS table as the connection table, whereas some others like RSMeans and activities have a one to many relation. Few tables have one to one relations. Tables and their relations are depicted in the following diagram. The entities involved are as follows:

- Project: This is where the ID and description of each project is stored. The managers are also identifiable by the project they manage. It has a many to many relation with Total Floats and Discipline tables through WBSs table.
- Discipline: This is where the different disciplines of the project, for instance: civil, electrical, etc. are stored. Its ID is a foreign key to WBSs table.
- Managers: This table is where the information pertinent to managers is kept. It acts as a foreign key to Projects table.
- WBS: This table is where the ID and description of each node on WBS is stored. It is in direct contact with Projects table.
- Total Floats: The total float value for each activity with a certain WBS ID is stored in this table. In light of the fact that total float per activity varies from period to period, the date, marking report date of total float is also incorporated in the Total floats table. By the same logic, project duration is included in the table as well. This entity is to service the selection step and weighting phase of the current status reporting module.
- Activities: Activity ID and description is stored in the Activities table. If the quantities of materials are to be extracted from the number of man-hour then use of RSMeans standards is a necessity. Therefore, the RSMeans ID is the link to the Activities table to create the required connection and mapping element between activity descriptions in project and in the RSMeans standards. It has a many to many relation with the Projects table via WBSs table. Planned, Total Floats, Reports and RSMeans get foreign key from the Activities table.

- RSMeans: The data regarding RSMeans cost data book is stored in this table in case there is the need for conversion of man-hours to quantities of materials. It is in direct relation to Activities table.

- Planned: This table is where all the planned data is located. The data usable for the purpose of current study are planned start and finish dates of each activity, which are used in calculations for the planned quantity to date. Planned quantity that is the total quantity of material each activity consumes to accomplish its scope and is what the Pl_Quantity field refers to. Planned man-hours are dedicated a field in this table as well in case, conversion of man-hours to quantities via RSMeans is required.

- Reports: This table is one of the essential entities where the data that changes at different report dates is kept: Actual starts and finish date of each activity, BCWS and BCWP, actual quantity, actual man-hour, percentage complete of each activity, the date of the report, replenished quantities and current inventory quantity. It has the Activity ID and Material ID as foreign keys.

- Materials: This table concerns the type of data that doesn't change over time and are pertinent to materials and are used in corrective action component of the method, where the suggested casual factors are those complying to the information housed in this table. That is if a material happens to have a MSI<1 and the “deterioration” field for it is checked positive in this table, it means that the "Deterioration" of such material can potentially be the cause of delay so that user can further verify or investigate root cause of delay.

- Expected Impact: This table is used in storing the expected impact inputs from the user and generating the report for the use of @ Risk. Material ID serves as the foreign key for this table.

- Causal Factor: This entity is used for storing causal factors that are used as checklist in selection of materials, corrective actions and adjustment of selected individual MSIs for forecasting.

- Calculated MSIs: This entity stores the data pertinent to values of individual MSIs once calculated. Report ID and Material ID are linking this entity to the materials and reports table respectively.

- Calculated MSIts: This table stores the calculated MSIts. MSIts are mapped directly to the Projects table.

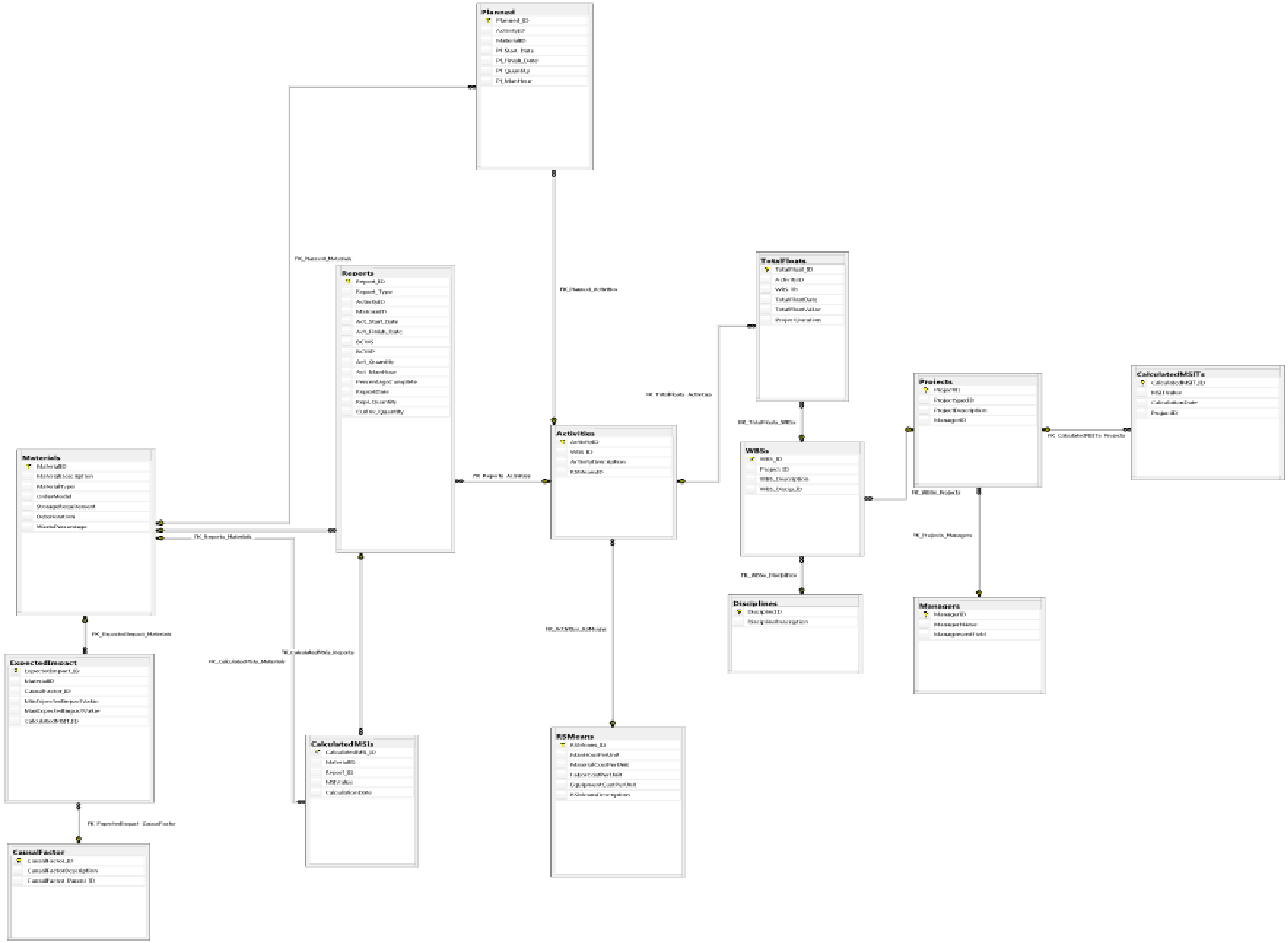


Figure 4-10- Developed database, entities and relations

4.4 Summary

The developed prototype was discussed in this chapter. It is coded using C# programming language. There are three main components in the application: database, graphical user interfaces and calculating algorithms. The developed software interacts with the user and @Risk software. The flexible design of the software promotes integration of implicit knowledge of project conveyed by project managers. The main advantage of the automated model is in expediting the process of obtaining schedule performance of projects. It also enables the user to effectively interact and make meaningful benefits from the project data..

5 CHAPTER FIVE: CASE STUDY AND VALIDATION

5.1 Introduction

This chapter is dedicated to two case studies and validation of the proposed method. To demonstrate the enhancements introduced by MSI in reporting the status of the project schedule and also in forecasting project duration, two case studies have been considered. Validation is considered a critical and complex task to fulfill. Since the method is designed to accommodate project specific conditions and user specific inputs, its validation is only viable by studying a real project that benefits from real user inputs for which there are actualized data available. The method is validated through its forecasting module for the most part. It is been made possible by comparing the forecast results of the proposed method and the existing forecasting methods with the actual completion dates observed real time on project. To this effect, two case studies have been presented.

5.2 Case studies

5.2.1 Case one: La Sarcelle Power Station

The first case is geared towards illustrating the processes and steps necessary to carry out in order to demonstrate the capabilities of the present method. 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.

Table 5-1- 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 1 illustrates the data used in the first study. The data pertinent to the shortlisted activities are included. Owing to the fact that bill of material was not included in the case documentations; materials used by each activity are adapted. To make valid assumptions on the quantities of materials consumed, RSMeans Heavy Construction Cost Data book-2010 is consulted. Materials are assigned to each activity. Some activities consume more than one type of material while some others, are not material driven activities and thus are not allocated any materials. Table 2 illustrates material assignments to each material.

Given that the original schedule is labor driven and all project costs originate from planned, actual and remaining man-hours, labor units used to install one unit of each item line of RSMeans cost data, are employed as the basis for quantities assumed to be consumed by each activity.

$$InsQp = Lup / LuRSMeans \qquad \textbf{(5-1)}$$

Where InsQp is the planned quantity of materials installed; Lup is the total planned labor units for period n and LuRSMeans is the total labor units required to install the unit quantity of corresponding cost item in the RSMeans cost data.

InsQa = Lua/ LuRSMeans **(5-2)**

Similar abbreviation notations are used for the actual values as well. Where InsQa is the actual quantity of materials installed; Lua is the total actual labor units for period n and LuRSMeans is the total labor units required to install the unit quantity of corresponding cost item in the RSMeans cost data.

Table 5-2- Critical and near critical activities considering selected material

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
MSI_t	0.447		
SPI	0.925		

Table 5-3- Critical and near critical activities considering all their material

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
MSI_t	0.417		
SPI	0.925		

Table 5-4- Critical activity considering selected material

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

Upon calculating MSIs and MSI_t to report on the current status of the project, the second module of proposed method is implemented. Different casual factors are selected per MSI for the three scenarios. The results of the study are illustrated in the following tables.

Table 5-5: 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
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 MSI 3 (No change)				
	Min	**Most Likely**	**Max**	**Defined dist.**
Mean				0.000

Table 5-6: 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 5-7: Causal factors considered per material-Scenario 2

Risk factor for MSI1 (Opportunities)				
Causal factor	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	MSI4	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 MSI5 (Opportunities)				
	Min	**Most Likely**	**Max**	**Defined dist.**
F1	1.000	1.000	1.000	1.000
Mean				1.000

Table 5-8: Adjustment of individual MSIs and calculation of forecasted duration-scenario 1

	Individual MSI	Risk Factor	Adjusted Individual MSI	Weight	Weighted adjusted individual MSI
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 5-9: Adjustment of individual MSIs and calculation of forecasted duration- scenario 2

	Individual MSI	Risk Factor	Adjusted Individual MSI	Weight	Weighted adjusted individual MSI
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 5-10: Adjustment of individual MSIs and calculation of forecasted duration- scenario 3

	Individual MSI	Risk Factor	Adjusted Individual MSI	Weight	Weighted adjusted individual MSI
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

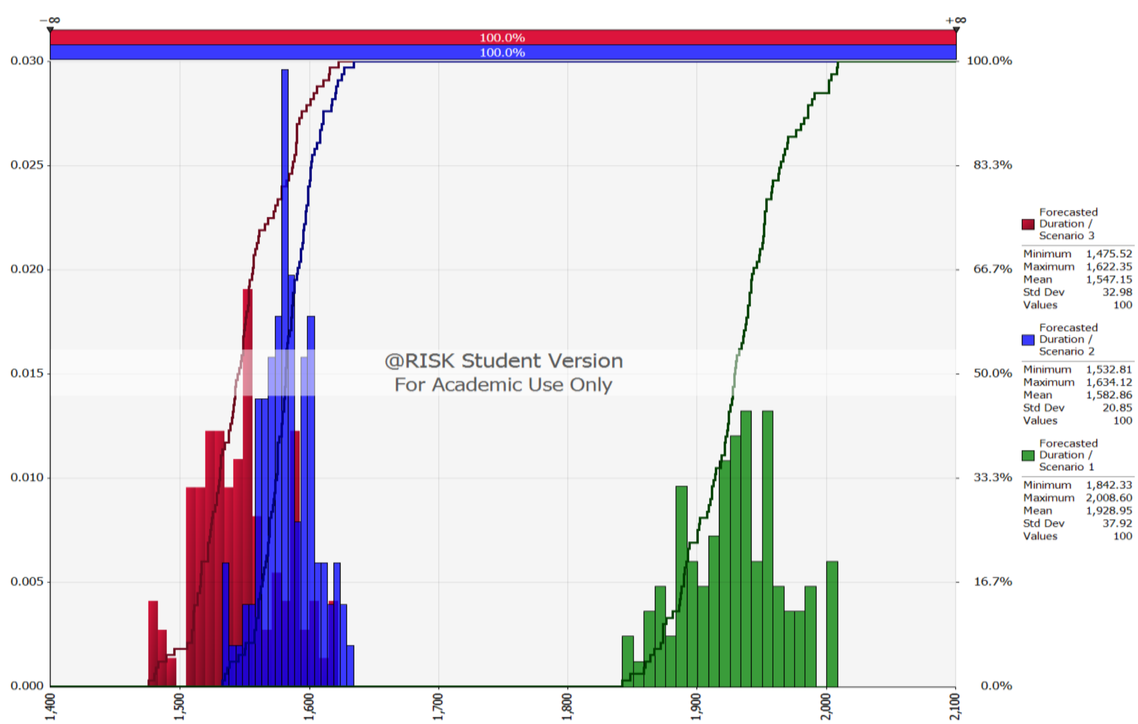
Table 5-11: R factor comparison of the three scenarios

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 5-12: 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

Figure 5.1- Forecasted duration distribution models of the three scenarios



5.2.2 Case two: Ultra low sulfur diesel facilities:

The second case study is intended to act as the validation of the proposed method to a greater extend. Upon enacting the Sulphur in Diesel Fuel Regulations (SOR/2002-254) by Canada, the sulphur content of diesel fuel produced or imported was reduced to 15 ppm after 31 May 2006, and projects to create the infrastructure for this refinement were introduced to contractors and bidders for involvement. Montreal refinery was among the locations to change its facilities for this purpose. This project consists of adding a new ULSD unit (Ultra low sulfur diesel) to the Montreal refinery and its entire associate site works. The work package under study presents the structural steel installation of the reactor and temporary structures for its erection. There are a total of thirty-eight activities, which can be mainly categorized, in the two steel structure work and finishing groups. Each group of activities requires one kind of material. As such there is only one material involved in the work package, steel. The material used for finishing activities has not been noted in the project documentations. Steel being considered as a critical material by the project expert, has been considered for calculation in this study.

There are six periods for which there are progress reports available. The first report belongs to construction start up; therefore due to scarcity of project data this period was not considered in calculations.

There are a total number of 38 detailed activities, which are rolled up in 9 activities at a higher WBS level. The only material noted in the reports is steel with a measurement unit of tonnage. Three groups of data were found in the document:

- Installed quantities for this material have been directly input into progress reports. There is also record of weekly tonnage installment of steel. These values have been used towards calculation of MSI.
- The number of man-hour, planned, spent on site for regular project scope as well as hours spent separately on change orders, which are employed to calculate SPI.
- Cumulative earned versus planned progress of project on a weekly basis, which illustrates the project scope (scope at the bid as well as change orders on site) progress status. This index has also been incorporated in comparisons and analysis of the results.

The duration is forecasted using 4 different methods:

- Industry partner' in house method: where the control team convenes for a brainstorming session and estimates the remaining work and completion dates for each activity.
- MSI
- SPI
- Earned vs. planned progress

Original duration is adjusted by the abovementioned methods by dividing the original duration of the project by the different indices. Forecasted duration and the values for different indices are tabulated below.

Table 5-13- Forecasted duration values for different indices considered

Indices	**April 18,2005**	**May 25,2005**	**June 17,2005**	**July 29,2005**	**August 12,2005**
MSI- Steel	1.155	1.020	1.030	1.040	1.060
SPI	1.311	1.280	0.956	0.929	1.003
Earned progress/planned progress	1.170	1.068	0.831	0.858	0.846
Forecasted duration					
1- Original duration	203.000				
2- Actual duration	210.000				
3- forecasted duration-industry partner	150.000	148.000	196.000	149.000	196.000
4- forecasted duration-MSI	175.700	219.020	197.087	195.192	191.509
5- forecasted duration-SPI	154.793	158.581	202.000	185.306	202.319
6- forecasted duration-earned vs. planned progress	173.469	190.005	247.000	235.445	239.972
Industry partner's formula error in forecasting	0.29	0.30	0.07	0.29	0.07
MSI error in forecasting	0.16	0.04	0.06	0.07	0.09
SPI error in forecasting	0.26	0.24	0.04	0.12	0.04

The value for the MSI and SPI across the five periods has been tracked in the following chart

Table 5-14- MSI values across all periods

Date	MSI
April 18,2005	1.16
May 25,2005	0.93
June 17,2005	1.03
July 29,2005	1.04
August 12,2005	1.06

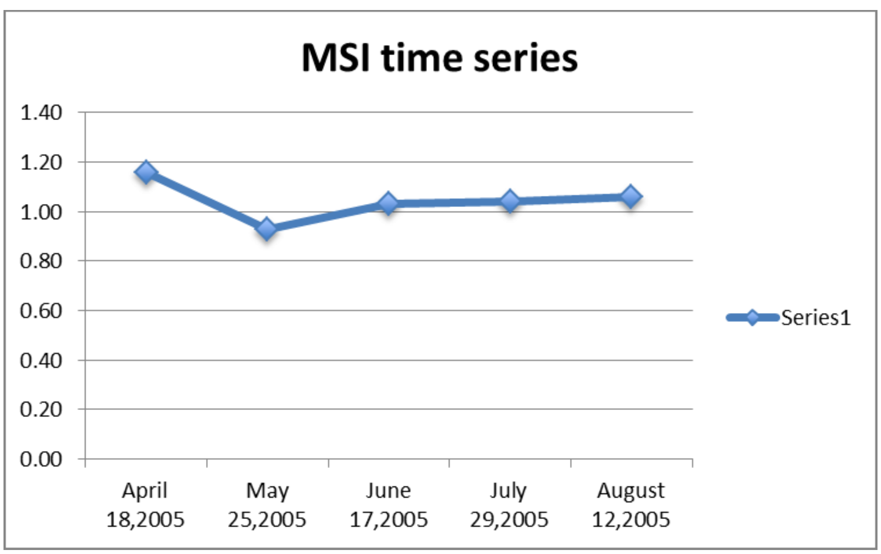


Figure 5-2- MSI fluctuation across five periods

The value for the MSI proves not to be very volatile over time and maintains slightly above and below 1, indicating that the project is on schedule.

Table 5-15- SPI value across five periods

Date	SPI
April 18,2005	1.31
May 25,2005	1.28
June 17,2005	0.96
July 29,2005	0.93
August 12,2005	1.00

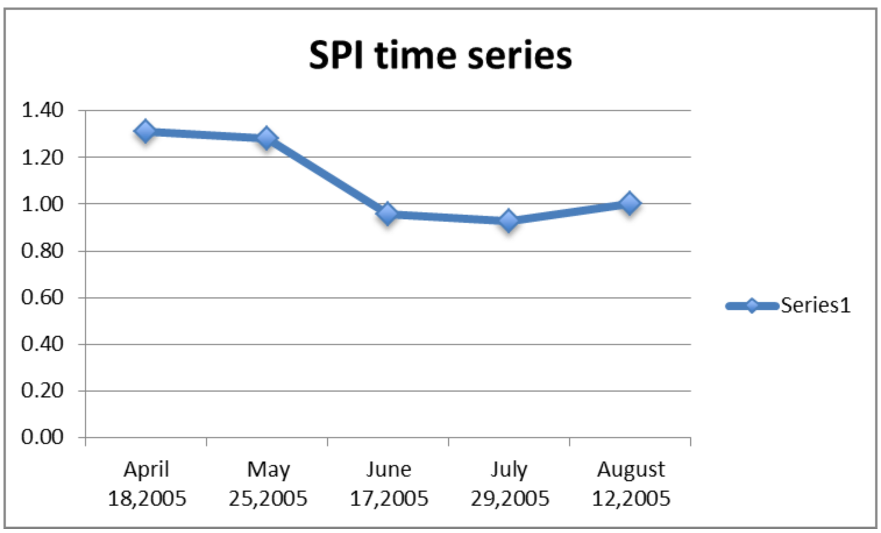


Figure 5.3- SPI fluctuation across five periods

Whereas the SPI has more fluctuation over time meaning that the status of non-critical activities has less stable. The values for the SPI are also centered on the value 1, with greater deviations from 1.

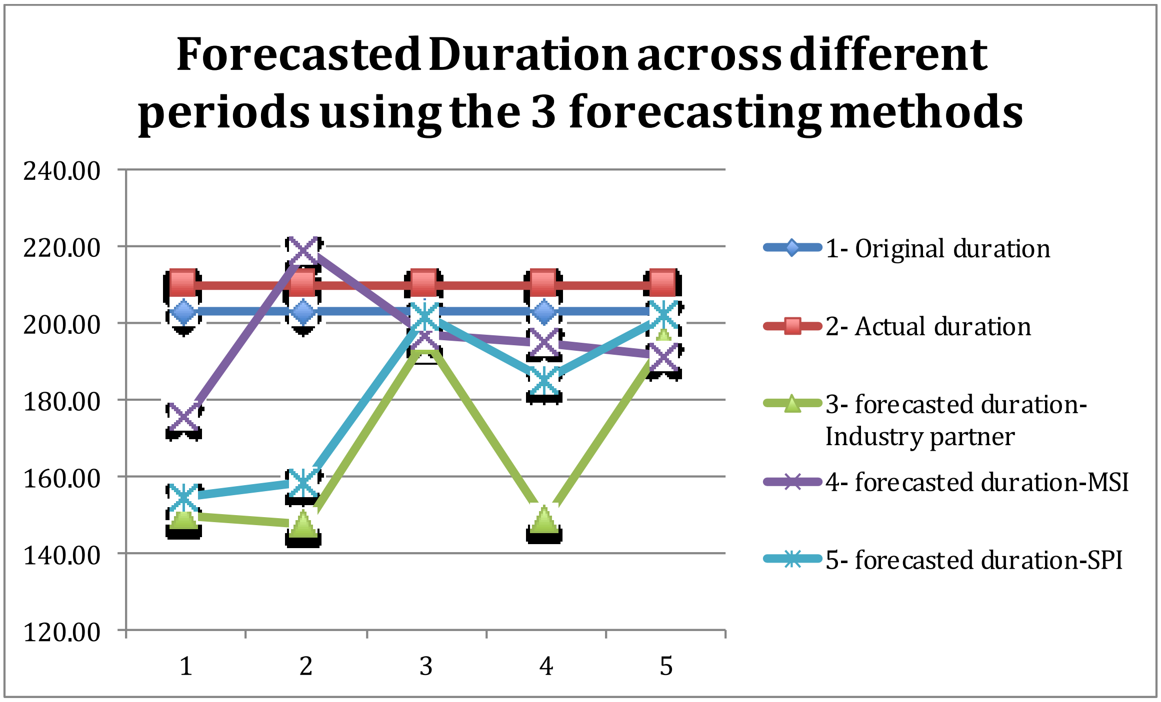


Figure 5-4 Forecasted duration across 5 periods using the 3 forecasting methods

Table 5-16- Joint interpretation of project status across five periods

Date	MSI	SPI	Schedule status
April 18,2005	1.16	1.31	Ahead of schedule
May 25,2005	0.93	1.28	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
June 17,2005	1.03	0.96	Project ahead of schedule but attention should be drawn to non-critical activities that are becoming critical. Attention should be drawn to escalation in cost of resources
July 29,2005	1.04	0.93	Project ahead of schedule but attention should be drawn to non-critical activities that are becoming critical. Attention should be drawn to escalation in cost of resources

Date	MSI	SPI	Schedule status
August 12,2005	1.06	1.00	Project ahead of schedule but attention should be drawn to non-critical activities that are becoming critical. Attention should be drawn to escalation in cost of resources

The forecasted duration employing the different methods across all the five periods and also across the different methods is illustrated in the charts of the following page.

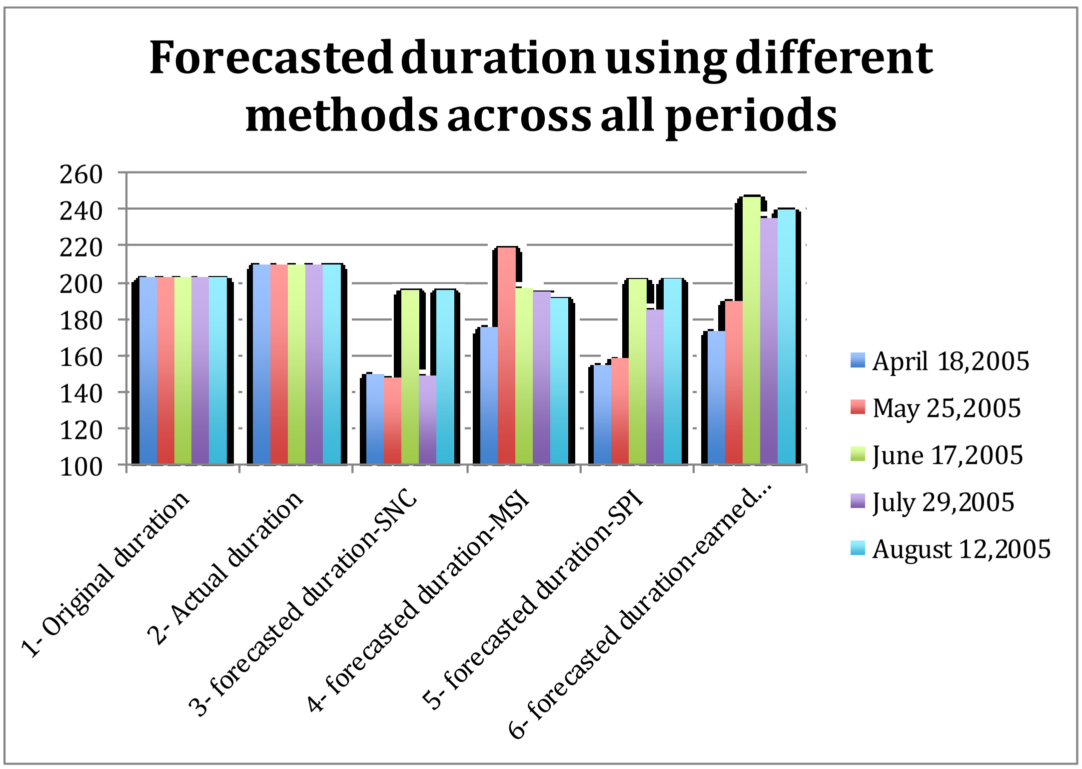


Figure 5-5- Forecasted duration using different methods across all periods

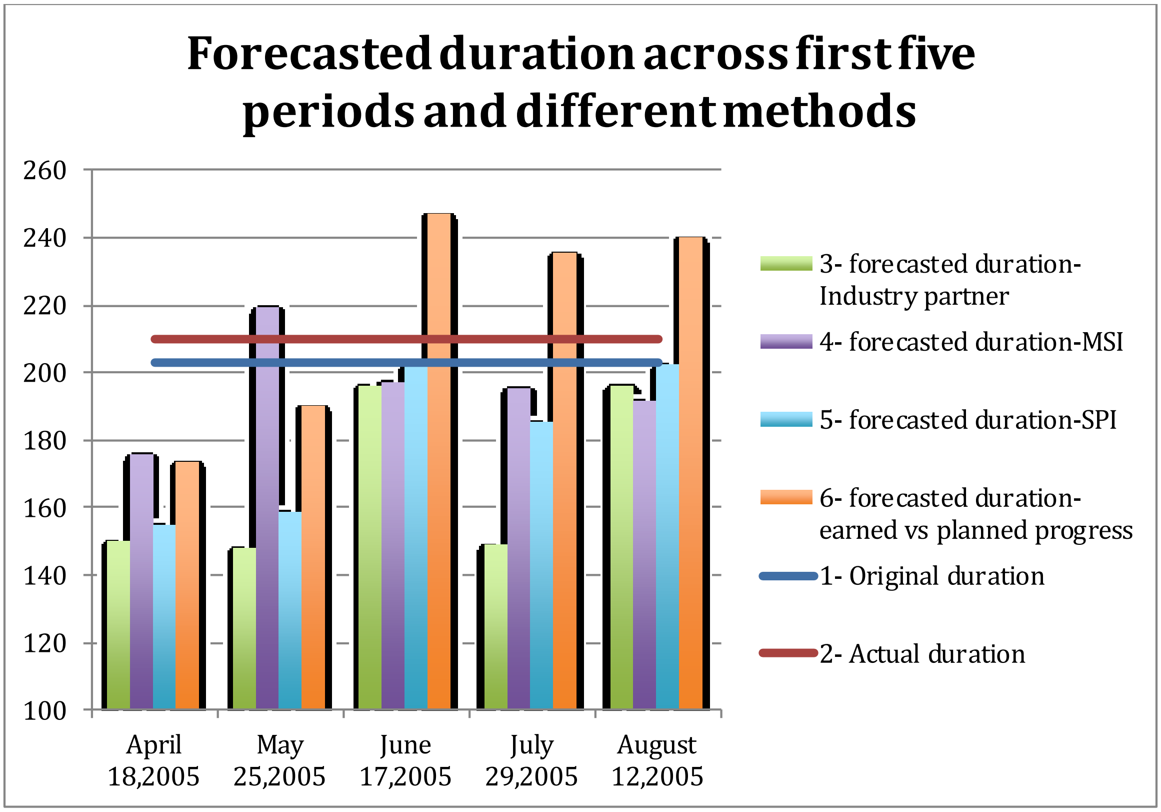


Figure 5-6- Forecasted duration across five periods and different methods

The charts above confirm that the MSI outperform SPI in forecasting the project duration. It delivers a closer result to the actual duration of project in three out of five periods and in the other two periods there exists negligible difference between the prediction results of the two methods. The forecasted duration using earned versus planned index found in the company reports, generates the least accurate set of project duration predictions. Results from the industry partner's in house forecasting method demonstrate frequent underestimation of the project duration

Decription	8-Apr-05	15-Apr-05	22-Apr-05	29-Apr-05	6-May-05	13-May-05	20-May-05	27-May-05	3-Jun-05	10-Jun-05	17-Jun-05	23-Jun-05	30-Jun-05	08-Jul-05	15-Jul-05	22-Jul-05	29-Jul-05	05-Aug-05	12-Aug-05	19-Aug-05	26-Aug-05	02-Sep-05	09-Sep-05	16-Sep-05	23-Sep-05	30-Sep-05	07-Oct-05	14-Oct-05	21-Oct-05	28-Oct-05
Structure permanente des réacteurs ÉRECTION									11	11	11	11	11	11																
Structure permanente des réacteurs ÉRECTION									1.00%	27.00%	45.00%	50.00%	70.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	85.00%	92.00%	95.00%	96.00%	97.00%	98.00%	99.00%	100.00%
Structure permanente des réacteurs ÉRECTION																														
Structure permanente des réacteurs FINITION										5.00%	25.00%	40.00%	50.00%	60.00%	65.00%	65.00%	65.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	80.00%	85.00%	88.00%	89.00%	90.00%	90.00%	100.00%
Escalier d'acier pour D-5101 et D-5102 (érection)											3	3	3																	
Escalier d'acier pour D-5101 et D-5102 (érection)										80.00%	80.00%	90.00%	90.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	98.00%	98.00%	100.00%					
Escalier d'acier pour D-5101 et D-5102 (érection)																														
Escalier d'acier pour D-5101 et D-5102 (finition)										1.00%	20.00%	60.00%	70.00%	80.00%	85.00%	85.00%	85.00%	95.00%	95.00%	95.00%	95.00%	95.00%	98.00%	98.00%	100.00%					
Structure temporaire pour le levage des réacteurs D-5101/D5102 (érection)									7.2	7.2	7.2	7.2	7.2	7.2																
Structure temporaire pour le levage des réacteurs D-5101/D5102 (érection)											40.00%	70.00%	90.00%	90.00%	95.00%	95.00%	95.00%	100.00%												
Structure temporaire pour le levage des réacteurs D-5101/D5102 (érection)																														
Structure temporaire pour le levage des réacteurs D-5101/D5102 (finition)											10.00%	40.00%	70.00%	80.00%	85.00%	85.00%	85.00%	100.00%												
Démontage de l'acier temporaire pour le levage des réacteurs D-5101/D-5102																			11	11	11	11								
Démontage de l'acier temporaire pour le levage des réacteurs D-5101/D-5102																						5.00%	15.00%	85.00%	100.00%					
Structure d'acier pour les séparateurs ÉRECTION					22.5	22.5	22.5	22.5																						
Structure d'acier pour les séparateurs ÉRECTION						30.00%	40.00%	60.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	98.00%	99.00%	100.00%								
Structure d'acier pour les séparateurs FINITION																														
Structure d'acier pour les séparateurs FINITION							10.00%	15.00%	28.00%	28.00%	28.00%	35.00%	45.00%	60.00%	70.00%	70.00%	70.00%	70.00%	75.00%	75.00%	85.00%	90.00%	95.00%	98.00%	100.00%					
Escalier d'acier no 3 et 4 des séparateurs (érection)									2.5	2.5																				
Escalier d'acier no 3 et 4 des séparateurs (érection)						35.00%	40.00%	100.00%																						
Escalier d'acier no 3 et 4 des séparateurs (finition)																														
Escalier d'acier no 3 et 4 des séparateurs (finition)							5.00%	41.00%	67.00%	67.00%	70.00%	75.00%	75.00%	85.00%	85.00%	85.00%	85.00%	95.00%	99.00%	100.00%										
Structure d'acier pour équipement F-5140 (Flare) ÉRECTION	9																													
Structure d'acier pour équipement F-5140 (Flare) ÉRECTION	100%																													
Structure d'acier pour équipement F-5140 (Flare) FINITION																														
Structure d'acier pour équipement F-5140 (Flare) FINITION	80%	80%	100%																											
Escaliers pour F-5140 (érection)	2																													
Escaliers pour F-5140 (érection)	100%																													
Escaliers pour F-5140 (finition)																														
Escaliers pour F-5140 (finition)	35%	35%	100%																											
Structure du "Feed" pour l'équipement F-5101 ÉRECTION				7.2	7.2	7.2	7.2	7.2	7.2																					
Structure du "Feed" pour l'équipement F-5101 ÉRECTION			10%	60%	95%	95.00%	95.00%	95.00%	100.00%																					
Structure du "Feed" pour l'équipement F-5101 FINITION																														
Structure du "Feed" pour l'équipement F-5101 FINITION				5%	40%	70.00%	80.00%	85.00%	85.00%	85.00%	85.00%	85.00%	85.00%	90.00%	90.00%	90.00%	90.00%	95.00%	99.00%	100.00%										
Escalier d'acier no.2 du "Feed" (érection)				2	2																									
Escalier d'acier no.2 du "Feed" (érection)				100%																										
Escalier d'acier no.2 du "Feed" (finition)																														
Escalier d'acier no.2 du "Feed" (finition)				12%	52%	87.00%	89.00%	90.00%	90.00%	100.00%																				

Table 5-17- Schedule of the work package with progress made till Dec 10 2004

5.3 Analysis and discussion of results

Results of the examined case studies prove that 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 project duration. Forecasting duration and reporting on schedule performance of project using MSI as a supplementary index is more accurate because of its consideration of level of criticality of project activities. Even if SPI is calculated based on only critical activities, MSI still benefits from its consideration of actual components of progress (quantities of materials) in calculations, because SPI is cost-based and cannot reflect the correct status of project. The mechanism that is suggested to be used in selecting only materials that are critical to the project duration, presents a further layer of accuracy. In addition, the adjusted MSI used for forecasting project duration provides a less subjective platform for the decision makers to account for uncertainties. Given that the forecasted duration using MSI exhibits closer results to actual duration achieved on the project, the capabilities of the proposed MSI are validated to a greater extent.

6 CHAPTER SIX: SUMMARY AND RECOMMENDATIONS

6.1 Summary and contributions

This chapter is dedicated to outlining the findings of this research and its contributions. Limitations and suggested future work is next elaborated on. This research project aims to study impact of material quantities on schedule performance. That is to provide a supplementary index that is capable of complimenting the existing SPI metric of earned value method by tracking and monitoring material quantities as opposed to monetary values traditionally done by the SPI. The proposed Material Status Index (MSI) enhances the SPI on several fronts:

- Consideration of criticalities of materials and by extension activities,
- Bestowing a much more manageable list of activities and materials to consider and therefore downsizing the amount of effort required to consider them all,
- Consideration of components of progress in performance reporting rather than dollar values which provides a more accurate indicator of performance.
- Pointing to root causes of project schedule slippage, in case of a delay.

The developed method is consisted of two main modules: current status reporting and forecasting. Each of the two modules is composed of several components. Current status reporting module follows a four-step procedure: selection, calculation, joint interpretation and corrective actions. While the forecasting module is dependent upon 3 major steps: Selection, adjustment and calculation.

A list of seventy-eight causal factors is extracted from the literature, mainly from the CII, 2011 best practice on global procurement and material management. These factors are the probable causes of project delay attributed to materials during their entire life cycle in construction from supply chain till they are on site before acceptance and also after granted admission to the site. This list is refined by experienced practitioners in industry in terms of their applicability to first construction projects in general and second in chemical and petrochemical construction in particular. The refined causal factors are used in the proposed method in:

- Selection component of the both modules in order to postulate critical materials involved in the project
- Corrective action component of current status reporting module to point out the probable root causes of problem. Suggestions are made based on the respective originators of delay.
- Adjustment component of forecasting module as a means to provide insight into the probable risks associated with the future of materials in projects.

In view of the fact that an automated mechanism was emerged as the most convenient means to implement the newly developed method, an software application is developed. It is a standalone software that can be run on different versions of Windows® operating system. It was coded using C# programming language. There are three main components engaged in the developed software:

database, graphical user interface and a set of data processing algorithms. The prototype interacts with the user and the database. There are a total of nine windows designed to act as the interactive screens. The outputs of the software are directly the expected outputs of the proposed method.

As for the last step in this study, in an effort to demonstrate the capabilities of the MSI method, it is implemented on two case studies. The first study is geared towards displaying the input, process and outputs of the proposed method; whereas the second study is mainly presented to validate the method, by comparing actual results of a real construction project with the forecast made by the MSI. It was observed that due to consideration of factors mentioned earlier, this model is capable of offering enhancements to the existing SPI metric.

6.2 Future work

As MSI is a newly proposed and developed concept in the domain of performance evaluation in construction project control, this cutting edge idea and the proposed method set the ground for future work in this field; taking an alternative approach in performance measurement. This study has paved the way for numerous further works on this topic, including:

- Proposing solutions to mitigate the aforementioned limitation of the method (elaborated on in chapter 3)

- Development of the MSI metric for different other phases of project life cycle aside form installation, for instance: procurement, engineering, commissioning.
- Development of implementation of the method on real project sites, that is to further develop automated supply of data for the use of this method and its seamless interactions with material management systems.
- Developing a systematic model to support decision-making using the proposed checklist of casual factors to act as the criteria to select critical activities.
- Developing other selection criteria to identify criticality of activities, rather than total float and float percentage.
- Studying joint interpretation of MSI with other project performance indicators such as cost performance index of EVM.
- Implementing and examining other forecasting formulas and scenarios using Material Status Index
- Investigate effects of density functions other than symmetrical triangular model as per the defined distribution for inputs of the forecasting module.

7 References

Wayne, & Abba, F. (2009). EVM in government: Striking a balance. Journal of software tech , 12 (1), 8-11.

Wang, L. C., Lin, Y. C., & Lin , P. H. (2007). Dynamic mobile RFID-based supply chin control and management system in construction. Advanced engineering informatics J. (Elsevier) , 377-390.

Wang, M.-J., & al, e. (2005). Solution to the unequal area facilities layout problem by genetic algorithm. Journal of computers in industry (Elsevier) , 56, 207-220.

Ward, S. A. (1980). Cost control in design and construction . Newyork: McGrow-Hill.

Wicjramatillaka, D. C., Koh, L., & Arunachalam, S. (2007). Measuring performance within the supply chain of a large scale project. Supply chain management: an international J. (Emerald) , 12 (1), 52-59.

Vandevoorde, S., & Vanhoucke, M. (2006). A comparison of different project duration forecasting methods using earned value metrics. International journal of project management (Elsevier) , 289-302.

Vanhoucke, M. (2011, 12 30). Why projetc control works so well for some proejcts and fails miserably for others. Retrieved 06 10, 2012, from PMI Knowledge Center: http://www.pmknowledgecenter.com/dynamic_scheduling/control/why-project-control-works-so-well-some-projects-and-fails-so-miserably-others

Vanhoucke, M. (2008). Earned value forecast accuracy and activity criticality. The measurable news (DoD) (summer), 13-16.

Vanhoucke, M. (2009). Measuring time: Improving project performance using earned value management. New York: Springer.

Vergara, A. B. (1974). Probabilistic approach to estimating and cost control. J. Constr. Div., ASCE , 100 (4), 543-552.

Building research establishment. (1981, March). waste of building materials. Building research establishment digest , 247.

Ballard, G. (2008). The lean project delivery system: An update. Lean construction J. , 2008, 1-19.

Bandyohpadhyay, e. a. (2002). A study on material procurement and management for small companies. American sociatey for engineering education- annual conference and exposition. session 2121. American society for engineering education.

Bossink, B., & Brounwers, H. (1996). Construction waste: quantification and source evaluation. J. of construction engineering and management (ASCE) , 122 (1), 55-60.

Callahan, M. .., Quanckenbush, D. G., & Rowings, J. E. (1992). Construction project scheduling. New York: McGraw-Hill, Inc.

Cioffi, D. F. (2005). A tool for managing projects: an analytic parametrization of the S-curves. Int. J. project managent (Elsevier) , 23 (3), 215-222.

Cha, H. S., Kim, J., & Han, J.-Y. (2009). Identifying and assessing influence factors on improving waste management performance for building construction projects. J. of construction engineering and management (ASCE) , 135 (7), 647-656.

Chen, S., & Zhang, X. (2012). An analytic review of earned value management studies in the construction industry. Construction research congress (CRC) , 236-246.

Construction Industry Institute (CII). (1987). Project control for contruction (Publication 6-5 ed.). Austin: The University of Texas at Austin.

Construction Industry Institute(CII). (2011). Global procurement and material management. Austin, TX: The University of Texas at Austin.

Cooper , K. (2003). Your projects real price tag- letters to the editor. Harward Bus. Rev. , 81 (12), 122.

Edward Back, W., Mata, F., & Barraza, G. A. (2004). Probabilistic forecasting of project perfromance using stochastic S-curves. J. constr. Eng. Manage., ASCE , 130 (1), 25-32.

Fleming, Q. W., & Koppelman, J. M. (2005). Earned value project management. Newtown Square, Pa, USA: Project Management Institute (CII).

Guthrie, P., & Mallett, H. (1995). Waste minimalisation and recycling in construction- A review. London, UK: CIRIA.

Gavilan , R. M., & Bernold, L. E. (1994). Source evaluation of solid waste in building construction. Journal of construction engineering and management, ASCE , 120 (3), 536-552.

Hamilton Allen Booz Inc. (2003). Earned value management tutorial module 5: EVM conceprts and methods. US Departement of Energy.

Hongtoo, M. (2010). The design of material delivery system based on lean construction. Journal of logistic for sustained economic development (ASCE) , 1796-1802.

Jaillon, L., Poon, C. S., & Chiang, Y. H. (2009). Quantifying the waste reduction potential of using prefabrication in building constrcution in Hong Kong. Waste management , 29 (1), 309-320.

Jalali, S. (2007). Quantification of construction waste amount. 6th nternational technical conference of waste. Viseu.

Jang, H. (2006). Optimization of floor-level construction material layout using Genetic Algorithm. Automation in contruction J. (Elsevier) , 16, 531-545.

Kim , E., Wells Jr., W. G., & Duffey, M. R. (2003). A model for effective implementation of earned value management metholdology. International journal of project management (Elsevier) , 21 (2003), 375-382.

Kim, B. C. (2007). Forecasting project progress and early warning of project overruns with probabilistic methods. PhD. dissertation . Texas: Texas A&M University.

Kim, B.-C., & Reinschmidt, K. (2010). Probabbilistic forecasting of project duration using Kalman filter and the earned value method. J. of construction engineering and management (ASCE) , 136 (8), 834-843.

Kim, S., & et al. (2011). Material management system based on the daily work. Journal of advanced material research (TransTech) , 255 (260), 1587- 1591.

Kim, S.-C. (2009). project success indicators focusing on residential projects: Are schedule performance index and cost performance index accurate measures in earned value? Canadian journal of civil engineers (CSCE) , 36 (100), 1700-1710.

Koskela, L. (2009). What is lean construction? presentation . Montreal, QC, Canada: University of Quebec in Montreal- UQAM.

Lau, H. H., Whyte, A., & Law, P. L. (2008). Composition and characteristics of construction waste generated by residential housing projects. Int. journal of environmental research , 261-268.

Lennon, B., & Francis, A. (2010). Improving the practical application for monitoring project progress using the earned value method. Winnipeg: CSCE- General conference.

Lipke, W. (2004). Connecting earned value to the schedule. The measurable news (DoD) , winter, 6-16.

Lipke, W., Zwikael, O., & Anbari, F. (2009). Prediction of project outcome: The application of statistical methods to earned value management and earned schedule performance indexes. International journal of project management (Elsevier) , 27 (4), 400-407.

Love, P., Irani, Z., & Edwards, D. (2004). A seamless supply chain management model for construction. Supply Chain Management: An International Journal (Emerald) , 9 (1), 43-56.

Navon, R., & Berkovich, O. (2006). An automated model for materials management and control. J. of construction managemnet and economics (Taylor & Francis) , 24 (6), 635-646.

Ma, Z., Shen, Q., & Zhang, J. (2004). Application of 4D for dynamic site layout and management of construction projects. Automation in construction (Elsevier) , 14 (3), 369-381.

Masoudi, F. A. (2011). Quantification methods for construction waste generation at construction sites: A review. Jr. of advanced material research (TransTech) , 163 (167), 4564-4569.

Mendel, T. J. (1986). Project controls and material management. AACE transactions.

Moselhi, O. (2011). The use of earned value in forecasting project durations. Seol, South Korea: IAARC.

Moslemi Naeni, L., Shadrokh, S., & Salehipour, A. (2011). A fuzzy approach for the earned value management. International journal of project management (Elsevier) , 29 (2011), 764-772.

O'Brian , J., Plotnick, F., & . (1999). CPM in construction management. Hightstown, N. J. USA: McGraw-Hill Professional.

Poon, C. C., Yu, A. W., Wong, S. W., & Cheung, E. (2004). Management of construction waste in public housing projects in Hong Kong. Construction management and economics (Taylor & Francis) , 22 (7), 675-689.

Poon, S. C., Yu, A. W., & Ng, H. L. (2001). On-site sorting of construction and demolition waste in Hong Kong. Resources, conservation and recycling J. (Elsevier) , 32 (2), 157-172.

Project Management Institute (PMI). (2005). Practice standard for earned value management. Newtown Sqaure : Project Management Institute.

Project Management Institute (PMI), Inc. (2007). Practice standard for scheduling. Newtown Square, PA., USA: PMI(R).

Project Management Institute. (2004). A guide to the project management body of knowledge, third edition. Newtown Square.

Project Managemnet Institute. (2008). A guide to the project management body of knowledge(PMBOK(R) Guide) (4 ed.). Newtown Square: Project management institute.

Sacks, R., Treckmann, M., & Rozenfeld, O. (2009). Visualization of work flow to support lean construction. Journal of construction engineering and management (ASCE) , 135 (12), 1307-1315.

Said, H. M. (2010). Optimizing site layout and material logistics planning during the construction of critical infrastructure projects. PhD. thesis . Urbana,, Illinois, US: University of Illinois at Urbana-Champaign.

Short, J. W. (1993). Using schedule variance as the only measure of schedule performance. Cost Engineering (AACE) , 35 (10), 35-40.

Shtub, A. (1992). Evaluation of two schedule control techniques for the development and implementation of new technologies: A simulation study. R&D management (RADMA) , 22 (1), 81-87.

Solis-Guzman, J., Marrero, M., Montes-Delgado, M. V., & Ramirez-de-Arellano, A. (2009). A spanish model for quantification of construction waste. Journal of waste management (Elsevier) , 29 (9), 2542-2548.

RSMeans Engineering Dept. (2011). RSMeans heavy construction cost data. Kingston, MA: RsMeans; 25 edition .

Thomas , R. H., & Riley, D. R. (2005). Fundamental principals of site material management. Journal of construction engineering and management (ASCE) , 808-815.

Thomas, H. R., & Sandivo, V. E. (2000). Role of the fabricator in labor productivity. J. Constr. Eng. Manage (ASCE) , 126 (5), 358-365.

8 Appendix

8.1 Material assignment using RSMeans cost data

Table 8-1-Material assignment for the first case study

Activity group	Sub activities	Assumed labor contribution of each sub activity to install 1 unit of work	Material	Structural elements	Assumed labor contribution of each structural element to install 1 unit of work	Specification	Units
Concrete/Finishing/etching	Concrete	40.00%	Concrete	Beam	20.00%	Concrete used to construct beams (3500 psi), 5 kip per L.F, 25' span	C.Y.
				Column	20.00%	Concrete used to construct 36" diameter, average reinforcing	C.Y.
				Walls	10.00%	Concrete used to construct retaining walls (3000 psi), gravity, 4' high	C.Y.
				Slabs	20.00%	Concrete used to construct elevated slab, waffle cost, 30" domes, 125 psf Sup. Load, 20'span	C.Y.
				Foundation	30.00%	Concrete used to construct foundation mat (3000psi), over 20 C.Y	C.Y.
	Finishing	30.00%	-	Beam	20.00%	Finishing work regarding beams (3500 psi), 5 kip per L.F, 25' span	C.Y.

				Column	20.00%	Finishing work regarding beams 36" diameter, average reinforcing	C.Y.
				Walls	10.00%	Finishing work regarding beams retaining walls (3000 psi), gravity, 4' high	C.Y.
				Slabs	20.00%	Finishing work regarding beams elevated slab, waffle cost, 30" domes, 125 psf Sup. Load, 20'span	C.Y.
				Foundation	30.00%	Finishing work regarding beams foundation mat(3000psi), over 20 C.Y	C.Y.
	Etching *	30.00%	-	All	-	-	-
Crack injection	-	100.00 %	Epoxy	All	-	Epoxy injection, 1/8" wide, 12" deep	L.F.
Formwork/form removal/scaffolding/ water stop	Formwork and form removal	80.00%	Form	Beam	20.00%	Forms used to construct beams (3500 psi), 5 kip per L.F, 25' span	C.Y.
				Column	20.00%	Forms used to construct 36" diameter, average reinforcing	C.Y.
				Walls	10.00%	Forms used to construct retaining walls (3000 psi), gravity, 4' high	C.Y.
				Slabs	20.00%	Forms used to construct elevated slab, waffle cost, 30" domes, 125 psf Sup. Load, 20'span	C.Y.
				Foundation	30.00%	Forms used to construct foundation mat(3000psi), over 20 C.Y	C.Y.
	Scaffolding	15.00%	Metal planks	All	-	Planks, 2"*10"*16", labor only to erect & remove to over 50' high	Each
	Water stop	5.00%	Ribbed PVC	All	-	PVC , ribbed 3/16" thick, 4" wide	L.F.

Embedded piping	-	100.00 %	Steel pipes with grooved joints including fitting and valves	Half the elements	50.00%	5" diameter	L.F
				Half the elements	50.00%	24" diameter	L.F
Prefab concrete placement	-	100.00 %	Precast structural concrete	Beam	30.00%	Rectangular, 20' span,18"* 36"	each
				Columns	30.00%	Rectangular to 12' high, small columns, 20"*20"	each
				Slabs	40.00%	lightweight concrete channel slab, short pieces, 3-3/4" thick	S.F
Rebar	-	100.00 %	Averag	Beam	20.00%	Rebar used to construct beams (3500 psi), 5 kip per L.F, 25' span	C.Y.

			e rebar for unit C.Y. of concrete	Column	20.00%	Rebar used to construct 36" diameter, average reinforcing	C.Y.
				Walls	10.00%	Rebar used to construct retaining walls (3000 psi), gravity, 4' high	C.Y.
				Slabs	20.00%	Rebar used to construct elevated slab, waffle cost, 30" domes, 125 psf Sup. Load, 20'span	C.Y.
				Foundation	30.00%	Rebar used to construct foundation mat(3000psi), over 20 C.Y	C.Y.
Embarkement	-	100.00 %	Sandy clay and loam	All	-	from existing stockpile, no compaction, 300' sandy clay and loam	L.C.Y.
Electrical work/ducting/ MALT	Electrical work and ducting	70.00%	Conduit in concrete slab including termin	Half the elements	50.00%	Rigid galvanized steel,1-1/4" diameter	L.F.
				Half the elements	50.00%	Rigid galvanized steel,2" diameter	L.F.

			ations					
	MALT	30.00%	-	-	-	-	-	-
Preparation and treatment of foundation/cleaning/ wire mesh**	Preparation and treatment of foundation	-	-	-	-	-	-	-
	Cleaning	-						
	Wire mesh	-						
Boring**	-	-	-	-	-	-	-	-
Rail gantry crane**	-	-	-	-	-	-	-	-
Temporary wheeled bridge**	-	-	-	-	-	-	-	-

*Etching is not included in the RSMeans item for concrete work

**Activities that don't consume any material are not considered for extended study

8.2 Questionnaire

What is the questionnaire about?
What you will find in the following 4 pages is a set of causal factors that can be attributed to material procurement cycle that may 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
On site- after acceptance
These categories represent the first tier of hierarchy followed by a second and further tiers, where the last tier of this structure includes the causal factors.

How to fill the questionnaire?
Hierarchy of causal factors booklet:
To better describe at which stage of material procurement cycle the causal factors under study are found, the above described hierarchy for each category is contained in this booklet.

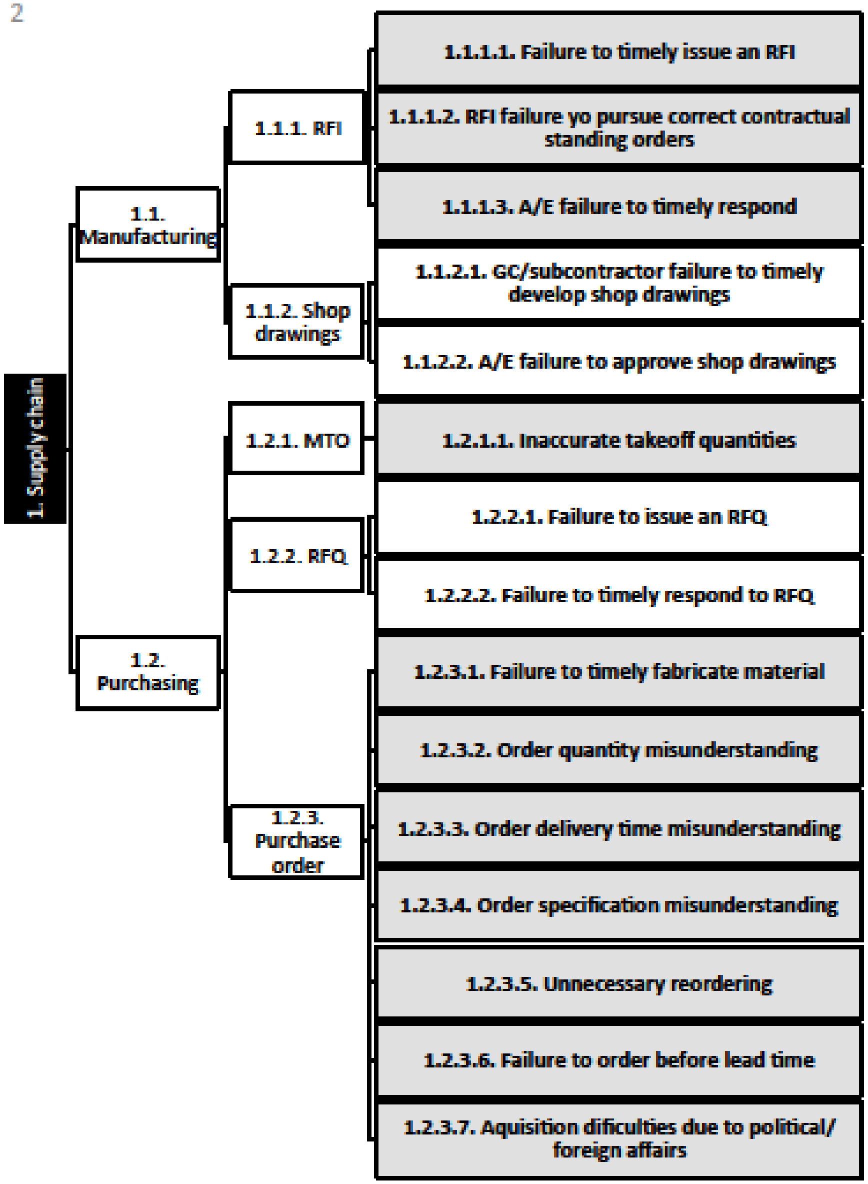
Tabulated answer booklet:
There are two of the same booklets to be filled in two separate rounds:
First round: To verify whether the factors sited are applicable in general and you would agree to consider them to cause delays. This step is geared towards refining the existing set of causal factors.
Second round: To verify whether the factors sited are applicable to your specific discipline in SNC-L and you would agree to consider them to cause delays. This step is geared towards creating a domain specific set of causal factors.

To verify please choose from one of the given choices below:
Accept:
    You would agree to consider the factor to cause delays
Delete:
    You would not agree to consider the factor to cause delays
Merge with:
    Factor seems to be redundant and could be joint with another factor
    Please write the number (e.g. 1.1.1.1 is the number for the "Failure to timely issue and RFI) of the factor to be joint with in the provided cell
Should you have more factors to add, please add them in the row named "Additions" located at the end of each group of factors.

I appreciate your valuable time, inputs and kind participation in our survey.

Table 8-2- Questionnaire

2



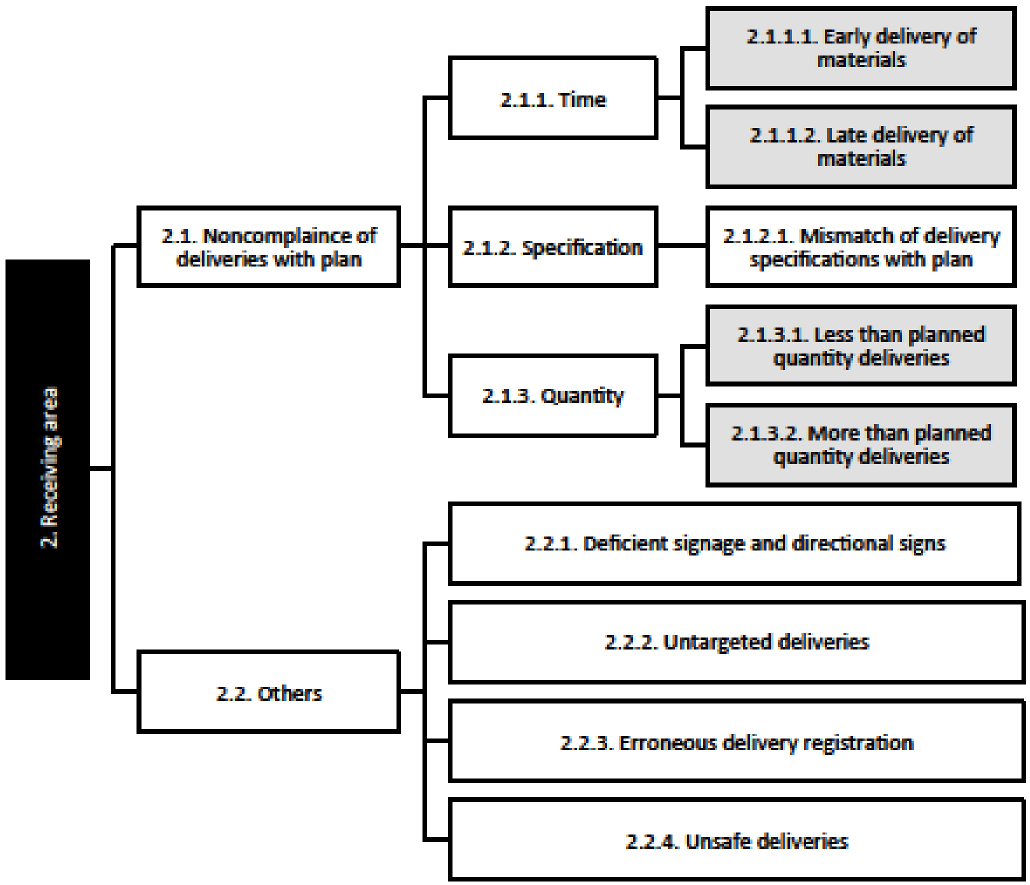
Causal Factor	Accept	Delete	Merge with
1.1.1.1.			
1.1.1.2.			
1.1.1.3.			
Additions			
1.1.2.1.			
1.1.2.2.			
Additions			
1.2.1.1.			
Additions			
1.2.2.1.			
1.2.2.2.			
Additions			
1.2.3.1.			
1.2.3.2.			
1.2.3.3.			
1.2.3.4.			
1.2.3.5.			
1.2.3.6.			
1.2.3.7.			
Additions			

3

- 1. Supply chain
  - 1.3. Expediting
    - 1.3.1. Status reporting & level 1
      - 1.3.1.1 Lack of information regarding order status
    - 1.3.2. Level 2
      - 1.3.2.1. Unavailability of detailed order schedule
      - 1.3.2.2. Unavailability of historical performance of suppliers
      - 1.3.2.3. Supplier unwillingness to cooperate
      - 1.3.2.4. Expediting difficulties due to second and third tier supplier
    - 1.3.3. Others
      - 1.3.3.1. Lack of experienced personnel
      - 1.3.3.2. Material expediting not coordinated with the erection sequence
  - 1.4. Inspection
    - 1.4.1. Quality assurance
      - 1.4.1.1. lack of adequate systems to deliver quality product
      - 1.4.1.2. Lack if ISO certification of supplier's QMS
    - 1.4.2. Quality control
      - 1.4.2.1. Failure to be validated as required specification
      - 1.4.2.2. Ascertaining difficulties regarding material's origins
      - 1.4.2.3.Non recognition of countefeit items
    - 1.4.3. Others
      - 1.4.3.1. Insufficient quality requirements (materials, processes and personnel) from owner and designer
  - 1.5. Transportation
    - 1.5.1. Freight issues
      - 1.5.1.1. Incorrect cost estimates
      - 1.5.1.2. Tarrif related issues
      - 1.5.1.3. Selection of unsuitable freight line
      - 1.5.1.4. Inaccurate routing guide
      - 1.5.1.5. Packing problems
      - 1.5.1.6. Inexperienced freight forwarders, marine surveyors and export pacers
      - 1.5.1.7. Surface handling problems
    - 1.5.2. Others
      - 1.5.2.1. Contractual issues
      - 1.5.2.2. Insurance related issues
      - 1.5.2.3. Security issues
      - 1.5.2.4. Government rules

Causal Factor	Accept	Delete	Merge with
1.3.1.1.			
Additions			
1.3.2.1.			
1.3.2.2.			
1.3.2.3.			
1.3.2.4.			
Additions			
1.3.3.1.			
1.3.3.2.			
Additions			
1.4.1.1.			
1.4.1.2.			
Additions			
1.4.2.1.			
1.4.2.2.			
1.4.2.3.			
Additions			
1.4.3.1.			
Additions			
1.5.1.1			
1.5.1.2.			
1.5.1.3.			
1.5.1.4.			
1.5.1.5.			
1.5.1.6.			
1.5.1.6.			
Additions			
1.5.2.1.			
1.5.2.2.			
1.5.2.3.			
1.5.2.4.			
Additions			

4



Causal Factor	Accept	Delete	Merge with
2.1.1.1.			
2.1.1.2			
Additions			
2.1.2.1.			
Additions			
2.1.3.1.			
2.1.3.2.			
Additions			
2.2.1.			
2.2.2.			
2.2.3.			
2.2.4			
Additions			

5

- 3. On site
  - 3.1. Storage
    - 3.1.1. Site laydown areas
    - 3.1.2. Warehouse
    - 3.1.3. Materials improperly sorted or marked
    - 3.1.4. Storing materials in temporary craft storage areas, shacks, gang boxes and staging areas
    - 3.1.5. Materials improperly sorted or marked
  - 3.2. Handling
    - 3.2.1. Insufficient rigging requiremnts
    - 3.2.2. In experienced workforce
    - 3.2.3. Extensive multiple handling of materials
    - 3.2.4. Trash or debris obscuring access to materials
  - 3.3. Waste
    - 3.3.1. Deterioration
    - 3.3.2. theft
    - 3.3.3. loss
    - 3.3.4. Inaccurate quantification of change orders
    - 3.3.5. Natural catastrophs
  - 3.4. Installation
    - 3.4.1. Unavailability of right equipment
    - 3.4.2. None supply of manifest or errection documents by supplier
    - 3.4.3. Unavailability of right crew
    - 3.4.4. Inexperienced workers
    - 3.4.5. Crew slow down in anticipation of material shortage
  - 3.5. Others
    - 3.5.1. Material possession conflicts between subcontractors
    - 3.5.2. Material related papaerwork
    - 3.5.3. Remobilization and refamiliarization after a lengthy delay

Causal Factor	Accept	Delete	Merge with
3.1.1.			
3.1.2.			
3.1.3.			
3.1.4.			
3.1.5.			
Additions			
3.2.1.			
3.2.2.			
3.2.3.			
3.2.4.			
Additions			
3.3.1.			
3.3.2.			
3.3.3.			
3.3.4.			
3.3.5.			
Additions			
3.4.1.			
3.4.2.			
3.4.3.			
3.4.4.			
3.4.5.			
Additions			
3.5.1.			
3.5.2.			
3.5.3.			
Addition			

8.3 Software application, loaded with the second case study data

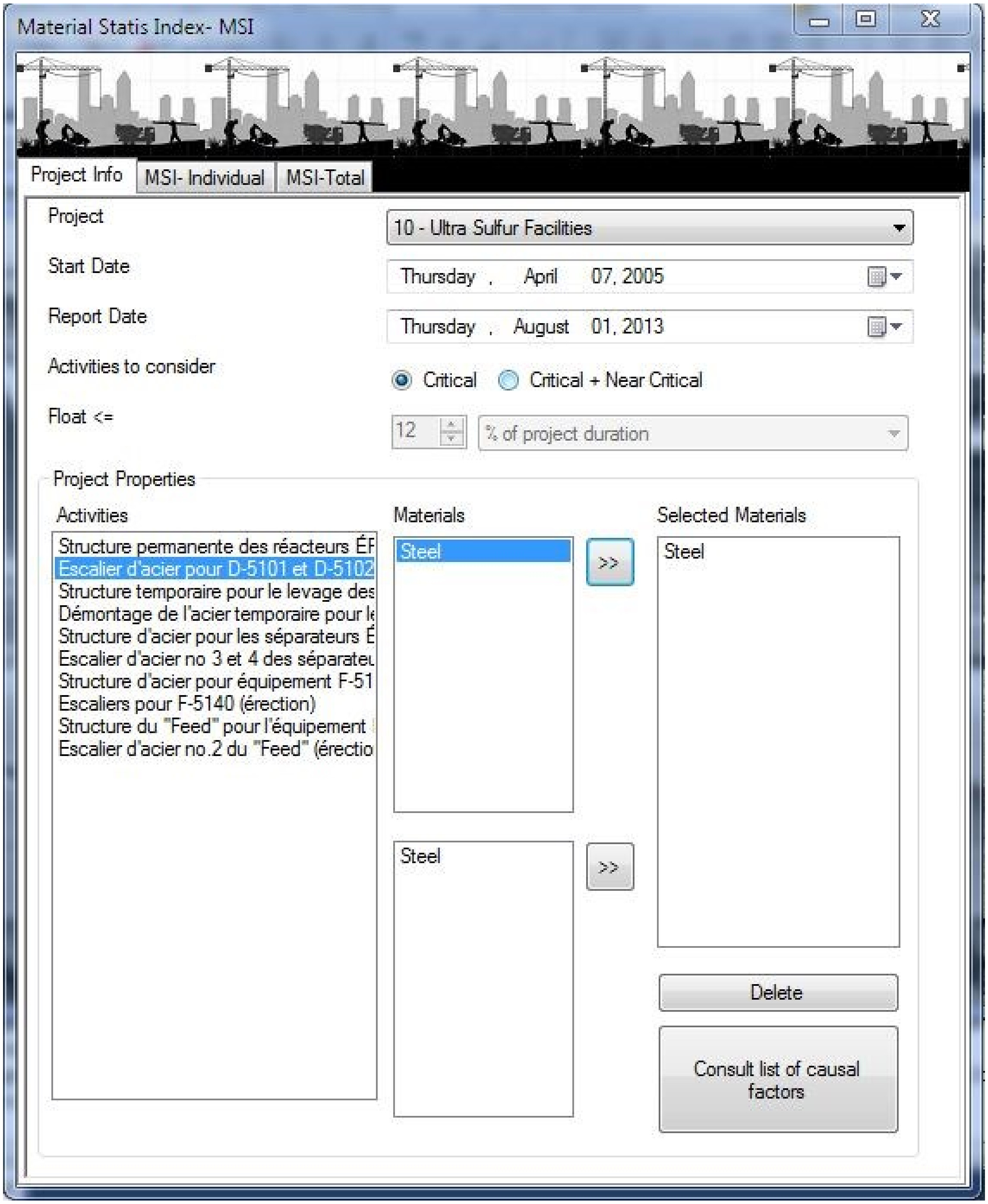


Figure 8-1-GUI- Current status reporting, project info

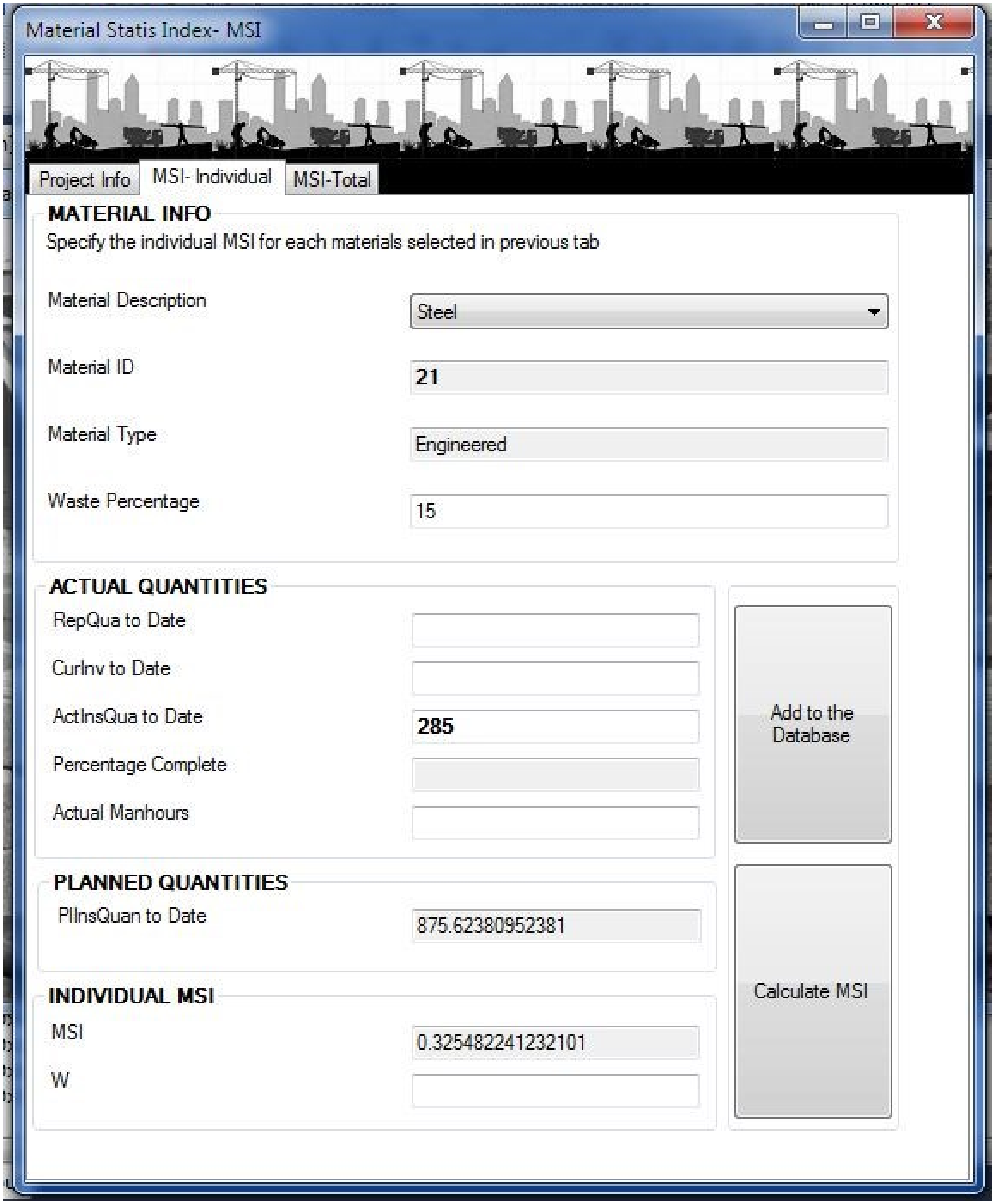


Figure 8-2- GUI- Current status reporting, MSI Individual

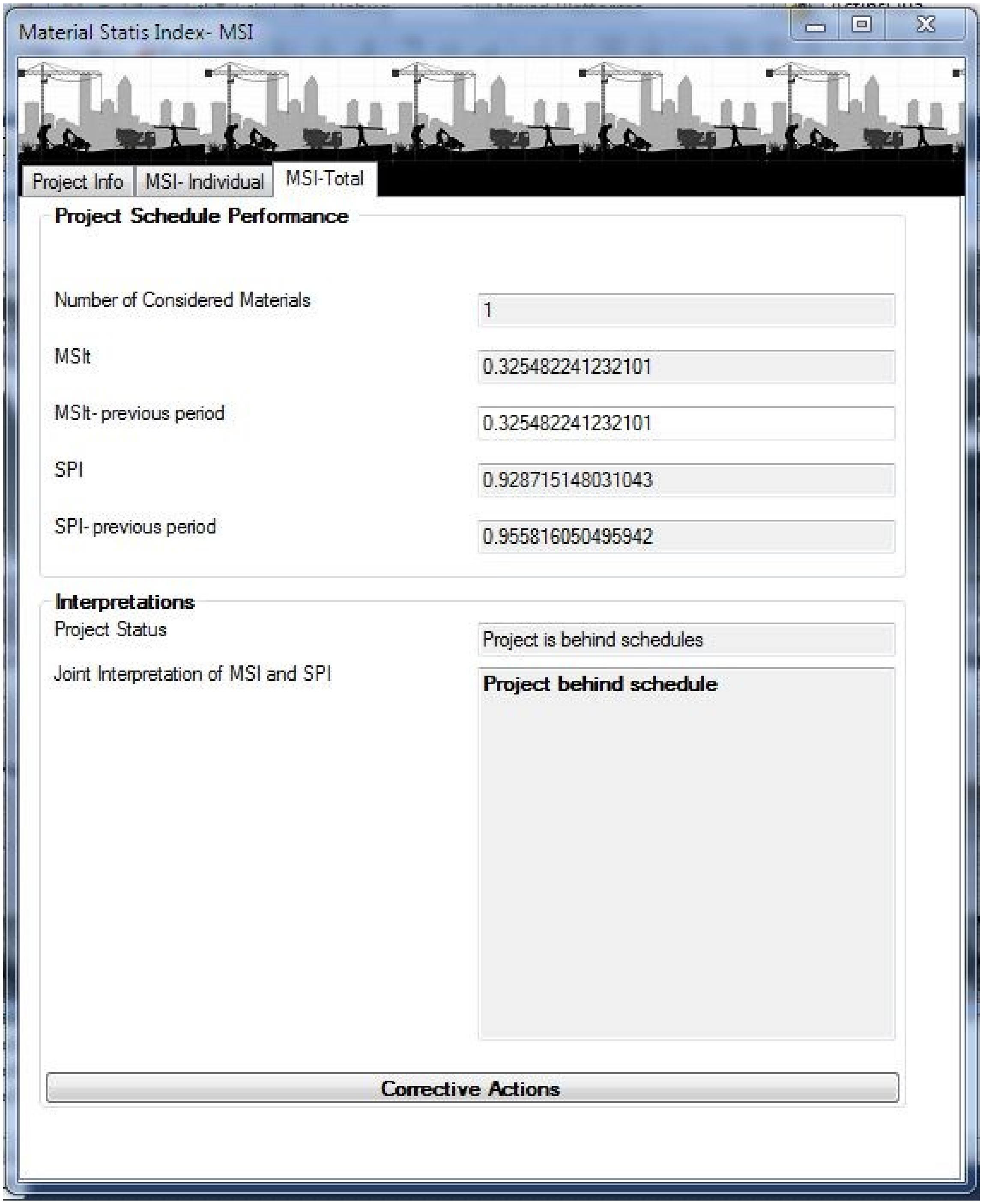


Figure 8-3- GUI-Current status reporting, MSIt

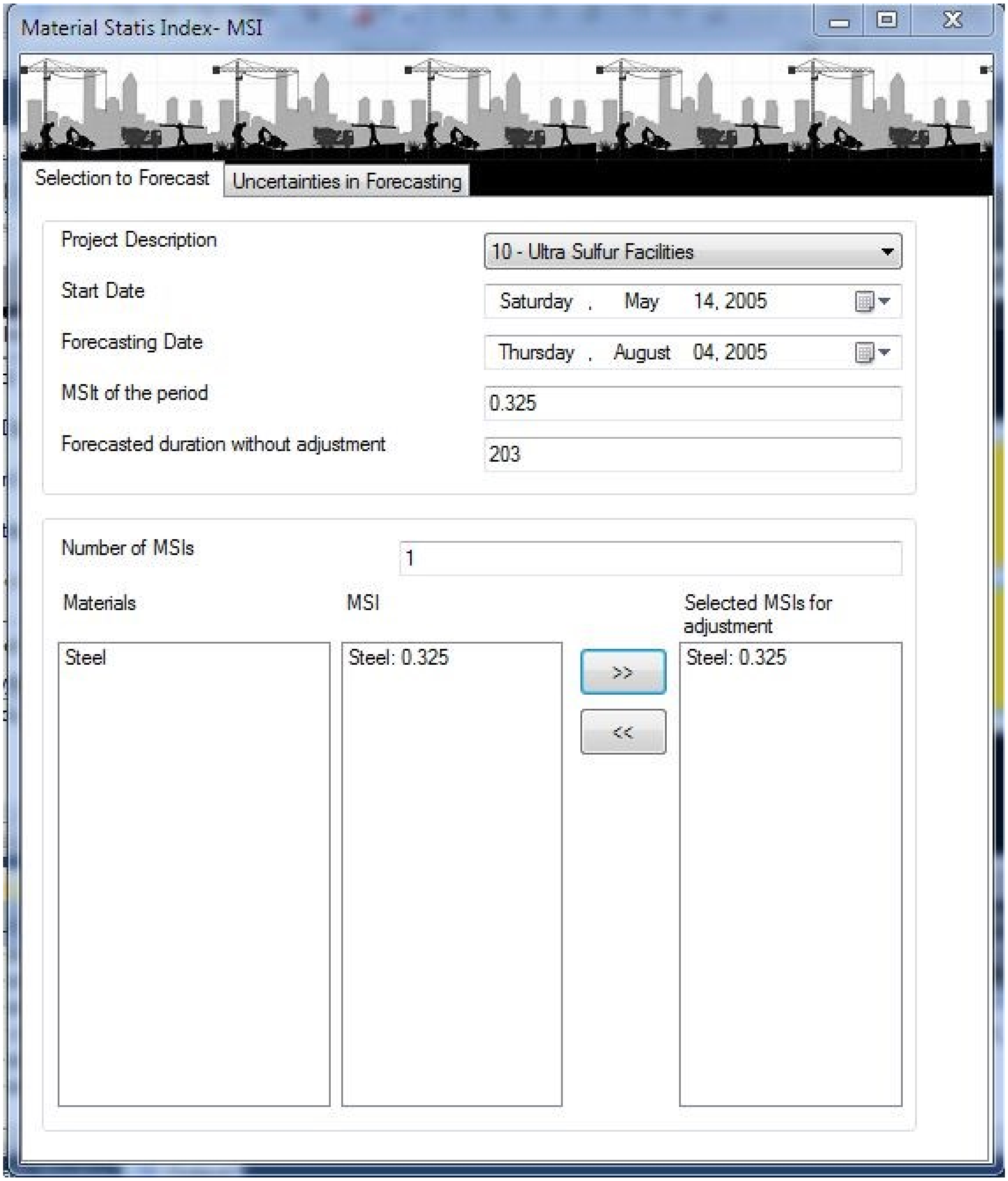


Figure 8-4- GUI- Forecasting, selection

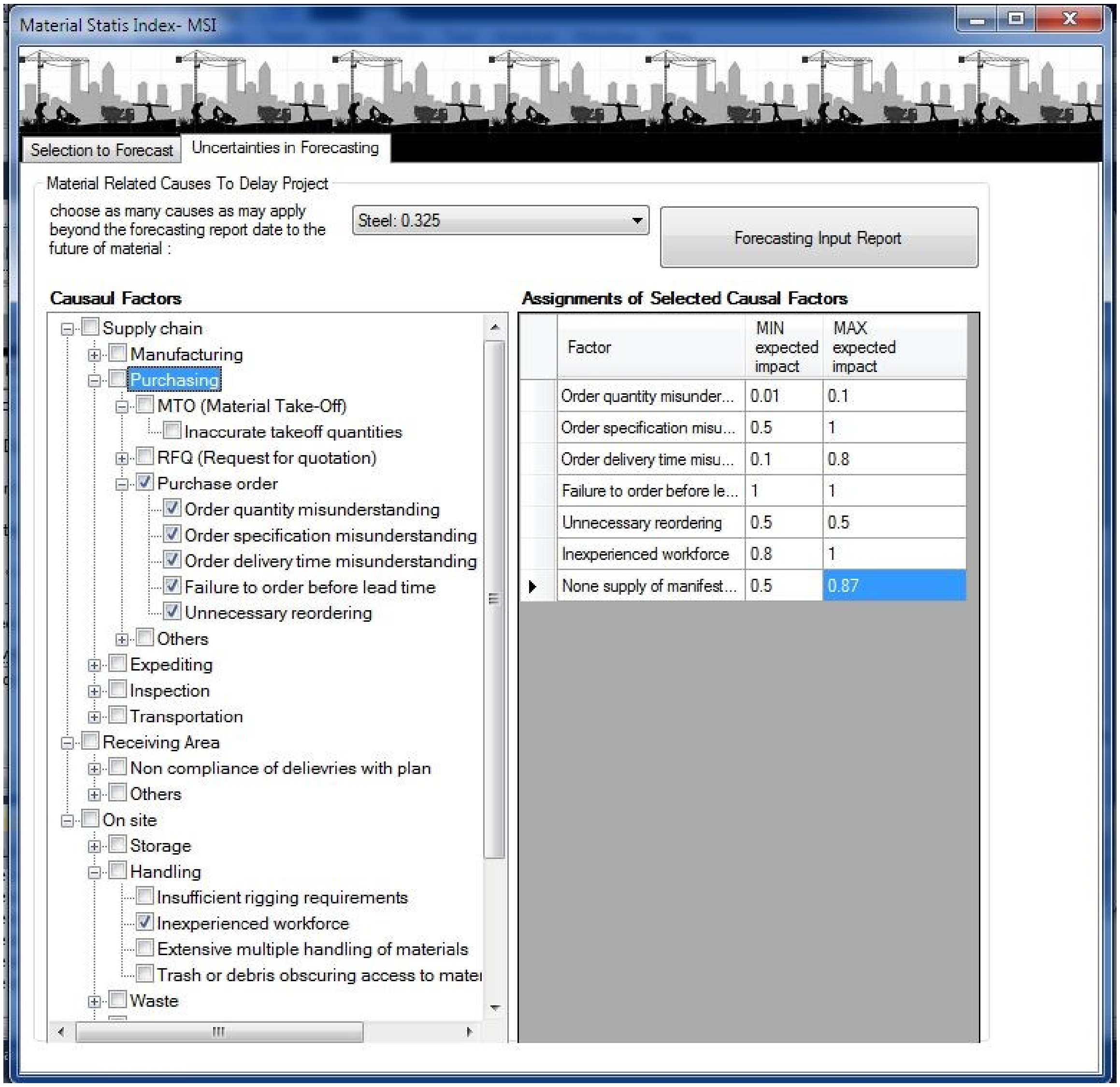


Figure 8-5- GUI- Forecasting, adjustment of MSIs and reporting to @Risk

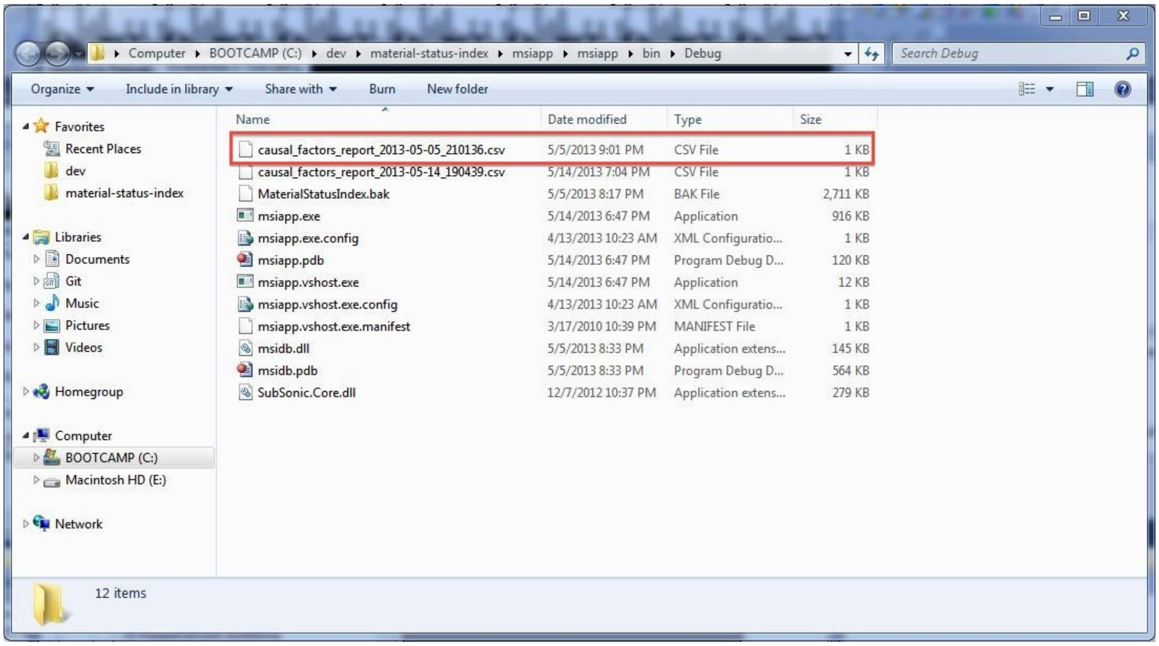


Figure 8-6- Software application report to @Risk

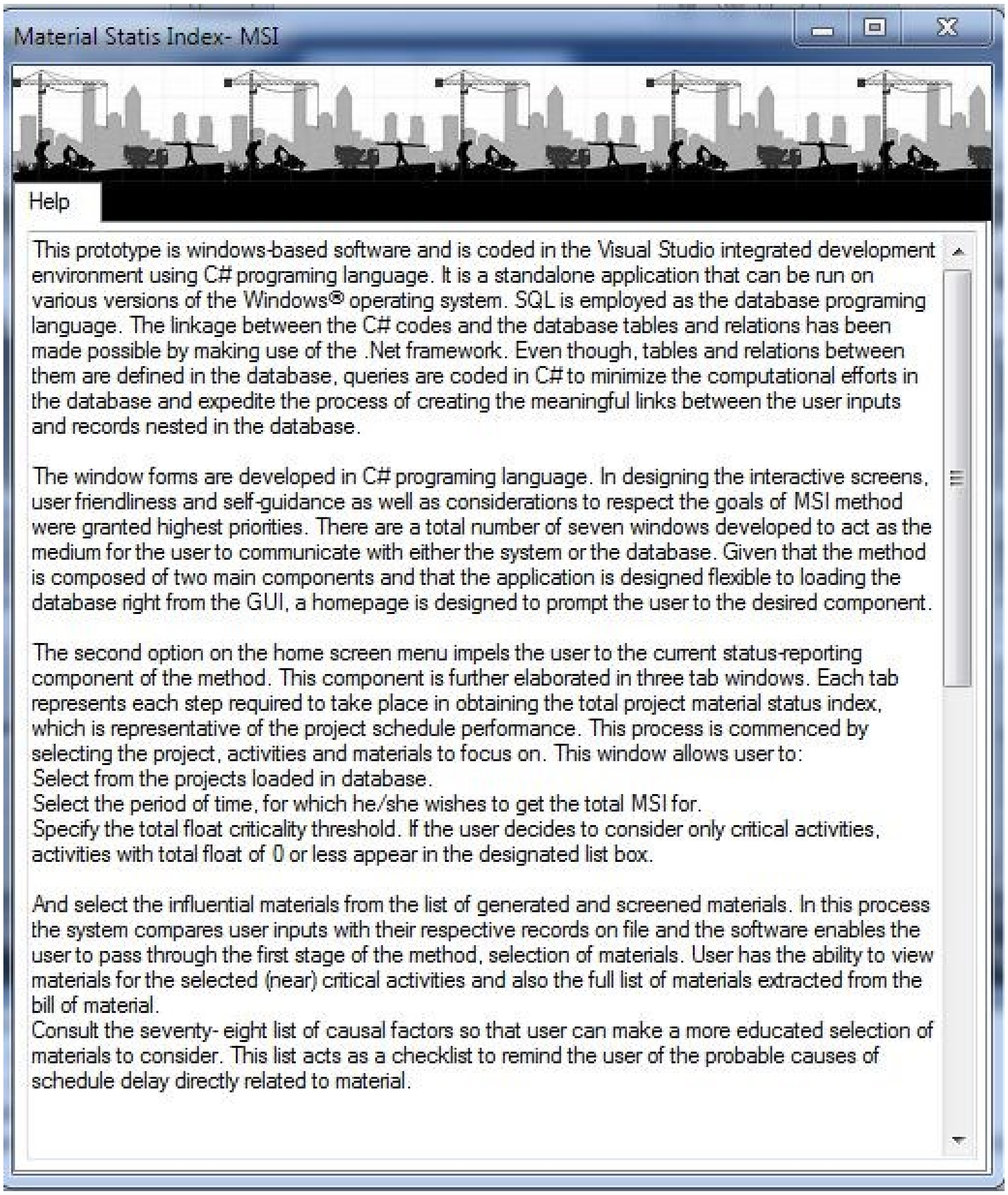


Figure 8-7- GUI, Help