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INTELLIGENT SUPPLY CHAIN VISIBILITY FOR CONSTRUCTION RISK MANAGEMET: A CASE STUDY FOR PIPE SPOOLS MANUFACTURING

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Abstract: In large industrial projects, substantial quantities of material are accumulated prior to construction in vast laydown yards and warehouses. The additional costs incurred by a project to accumulate and maintain these stockpiles can be enormous. On the other hand, the late arrival of materials often leads to extensive delays. To introduce supply chain management under dynamic risk, this paper introduces an intelligent framework for supply chain visibility and applies it to pipe spool manufacturing processes. The proposed framework has been designed to enhance risk management by helping decision makers promptly recognize the probability of occurrence of risk factors throughout the supply chain lifecycle. Using a case study, various risk factors were simulated in the @Risk software. The results indicate that efficient dynamic tracking of risk events increases supply chain visibility and leads to better assessment of the deviation in construction time and cost.

1 Introduction

A common problem in construction planning especially in large industrial projects is the material management, which is challenged by situations such as: lack of required materials, poor storage of critical equipment, improperly sequenced delivery of material, and overall process inefficiencies (Thomas, Riley, & Messner, 2005; Song, Haas, & Caldas, 2006; Razavi, et al., 2008). One of the main challenges facing construction managers is to keep track of all actions that take place on site in order to detect potential problems and to select appropriate corrective actions. Stockpiles of materials are a regular sight, especially in large projects. The additional costs incurred by a project to accumulate and maintain these stockpiles can be enormous (Hegazy and Menesi 2012; Kini 1999; Construction Industry Institute 1999). On the other hand, the late arrival of materials often leads to extensive delays that cause substantial overruns, thereby shrinking or eliminating project profit margins. The many risk factors that influence the progress of the supply chain become problematic when the probability of the occurrence of these factors and their impact are not well defined.

Much of the uncertainty, however, arises out of a lack of readily available and accurate information concerning the status of material at different stages within the construction supply chain. In other words, there is an overall lack of supply chain visibility (Razavi, et al., 2008). Supply chain visibility can be described as the degree to which a member of a supply chain has knowledge of the items being ordered or services states (Christopher and Lee 2004; Delen et al. 2007). The key to supply chain visibility is collecting and sharing of information among concerned members.In order to track the supply chain progress of multiple projects simultaneously, several techniques have recently emerged in the last two decades, including: radio frequency identification (RFID); global positioning systems (GPS); bar coding; and machine sensors (Jaselskis & El-Misalami, 2003; Logsdon, 1995). Automated tracking of materials on construction projects using these technologies has the potential to improve project performance (Futcher 2001; Kiziltas and Akinci 2005).

Because the probability of the occurrence of risk factors and their likely impact continue to change throughout the duration of a project, later recognition of these changes creates severe effects that are costly to manage. The use of automatic update system within the construction supply network presents a solution to these issues. This article presents an intelligent framework for supply chain visibility specifically for pipe spools processes for more efficient risk management. The proposed framework is designed to enhance risk management by helping decision makers recognize the probability of the occurrence of risk factors throughout the lifecycle of the supply chain. Pipe Spool was chosen for illustration as it is a common element in most industrial projects, and is known to suffer from the effects of uncertainty in the supply network.

2 Proposed Supply Chain Visibility Framework

To support efficient supply chain management, this paper proposes an intelligent supply chain visibility framework; which includes three main functions: (1) identification of possible SC-related risks; (2) automatic detection and updating of the probabilities associated with risk factors; and (3) performing sensitivity analysis and generating reports for decision makers. Figure 1 contains a schematic of the proposed framework, which incorporates the four components discussed in the following components:

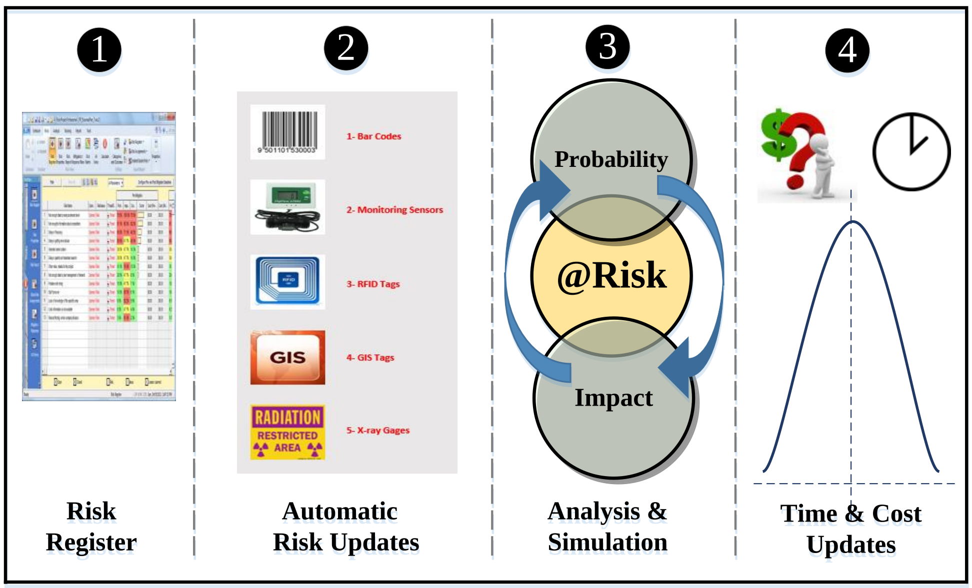

Figure 1: Proposed Framework

2.1 Risk Register

This component relates to the project activities that require supply chain management (e.g, pipe spool manufacturing). For each activity, the full supply chain lifecycle is analysed, which involves the following phases: S-specification; D-design; P-procurement; C-construction; T-transportation; and R-receive materials. An extensive study of the literature was conducted in order to develop an initial list of key SC risk factors that relate to all the SC phases. This list was then filtered based on experts to retain only the top factors that influence each supply chain phase. As such, a detailed risk register is developed, involving three types of data:

1. List of risk factors for each lifecycle phase: these key risk factors are quantitative and thus can be evaluated at different stages during construction. Automating the frequent updating of these factors is perceived as a means of greatly improving SC visibility;

2. Probability distribution curves: each risk factor is assigned a probability distribution curve that represents its default level of uncertainty; and

3. Impact on each lifecycle phase: different models have been utilized to quantify and store the impact of each risk factor on the activities' durations.

2.2 Supply Chain Visibility Tools

This component uses various tools for automatic collection of data that can update the risk factors. These tools include RFID tags; machine sensors; bar codes; X- Ray devices; and GPS tags.

RFID tags, Machine Sensors, and bar codes: Putting RFID tags on stacks means that we have information about the number of units ready for shipping at a specific time. Two types of data are collected from these devices are n, ti. Where n denotes for number units, while ti represents individual time for each unit. For example, consider an order of 100 stacks of steel sheets needs to be shipped together and the time required for preparing the stacks is 10 days (10 stacks per day). Using RFID tags for example provides up-to-date progress percentage for the stacks. Accordingly, it is possible to estimate the expected delay for this specific order (as Percentage) using Equation 1, as follows:

$$[1]\% \text{ Delay for a specific order } = \frac{\frac{\mathrm{N}}{\mathrm{P}} - D}{\mathrm{D}} * 100$$

Where, N is total number of units; D is planned duration for completing all units; and P is the actual progress rate determine from automated RFID readings.

The same approach can be used when collecting data with sensors and bar codes. The more the data is obtained automatically, the more accurate is the delay percentage. Early delay recognition, will help with better mitigating the risk of insufficient materials and resources.

X- Ray Devices: Using X- Ray devices helps to track the progress of the production. For each automatic update, the system receives the number of units passed the inspection or failed at specific time. Accordingly, the percentage of the delay can be calculated using the same Equation (1), while the failure rate can be calculated using Equation (2) as follows:

$$[2] \text{ Failure Rate } = \text{ Avg.}\left(\frac{\mathrm{N_{fi}}}{\mathrm{N_{fi}} + \mathrm{N_{pi}}}\right)$$

Where, N_{fi} is total number of units failed the inspection; N_{pi} is total number of units passed the inspection. N_{fi} and N_{pi} are determined from automated X-Ray readings.

GPS tags: GPS tags will be assigned to specific shipment, for example, when the order of hundred-pipe spool needs to be shipped once, one GPS tag can be assigned to the whole shipment. Assuming that the shipment will be transported by ship, and the distance is 900 km. The average speed of the ships is 30 km per hour. Therefore, the planned duration is 30 hours. The actual progress is achieved based on the information that founded from GPS devices. The percentage of the delay can be calculated using the Equation (1). GPS can help with lost items as well, and can be used for validation the transportation and environmental risk detection models.

2.3 Analysis and Simulation

The third component of the proposed framework is the analysis and simulation. Having the project risk register defined, a Monte Carlo simulation approach (as shown in Figure 2) is applied to quantify its impact of the project time and cost. The outputs of the simulation are probability distribution functions for the project time and cost. Before the project starts, the simulation produces default project time and cost probability functions. As the project progresses and the SC visibility tools collects automatic updates about the risk factors, there individual probabilities are adjusted and the simulation is rerun to produce modified probability distribution functions. These distributions are automatically and continually updated to support decision makers in their assessment of unforeseen factors related to their projects. To carry out the simulation, a commercial too, @Risk, has been used, and customized to interactively allow new updated information about risks to be considered at different project update points.

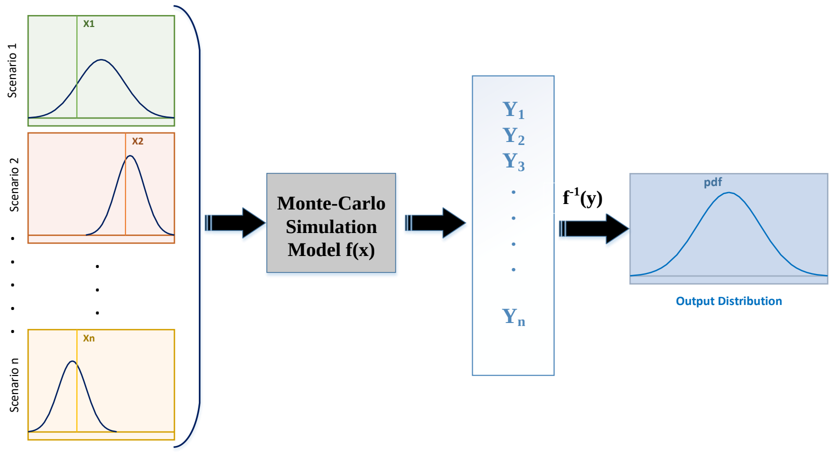

Figure 2: Monte-Carlo Simulation Approach

2.4 Project Time and Cost Update

In this component, an automated and iterative risk update process is carried out to keep monitoring all the supply chain activities at the same time (which experience different life cycle phases) using various SC visibility tools and accordingly update the project time and cost distributions, as shown in Figure 3. In this figure, it is assumed that a project includes 5 activities that require supply chain management along two project update times. Given that a detailed risk register is defined for all the activities, the analysis starts by performing Monte Carlo simulation using the default probabilities stored in the register. The project time distribution in this case is shown at the bottom., which exhibits a reasonable narrow range of project duration changes. Before the project started, At the first project update, the first activity experienced risk factors related to the transportation phase of the related items that are shipped at sea (as determined by a SC visibility tool such as extreme weather information). Accordingly, the distribution of activity 1 transportation time is adjusted by multiplying its original distribution by the delay % calculated from Equation 1. In the first update also, other risk events affected both activities 2 and 3. Based on the individual probability distribution modifications in project update 1, the Monte Marlo simulation is re-run, and accordingly, a new revised distribution function for the project duration is developed, as shown at the bottom of Figure 3.

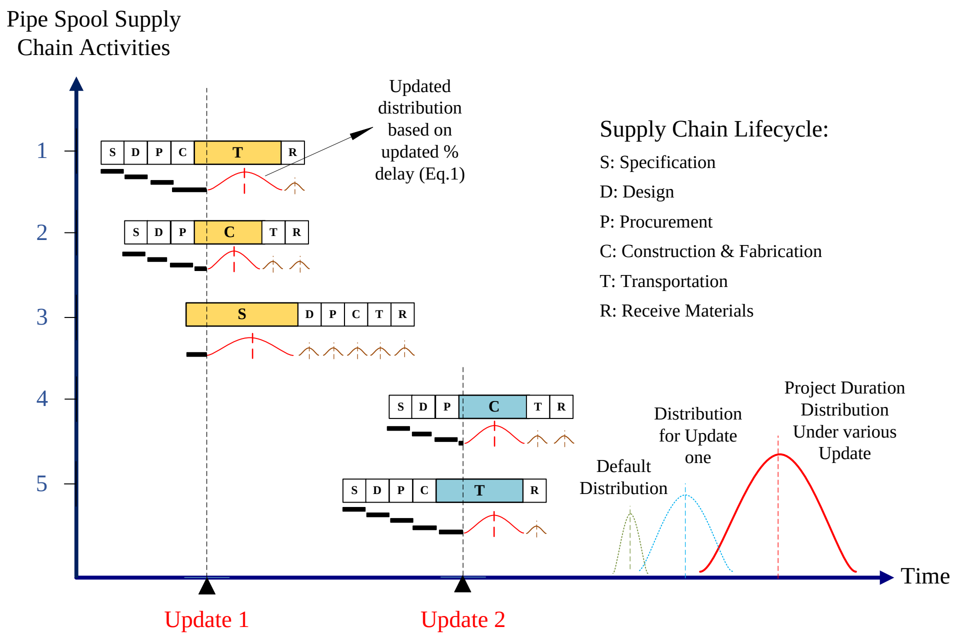

Figure 3Figure 3: Risk Probabilities for Key CSC Activities

The same process is followed at the second project update, resulting in a third revised distribution for project duration. The above process, as such, not only automates the tracking of risks, but also is capable of producing reports that better portray of the project duration distribution. These reports provide decision makers with information about the effects of the unforeseen risk factors and their impact on the project's cost and schedule. The main reason for using Monte Carlo Simulation in construction projects is to evaluate the enormous amount of calculations related to thousands of scenarios that consider many combinations of risk effects.

3 Case Study and Discussion

To demonstrate the practicality of the proposed framework and calibrate its functions, a real-life case study industrial project has been used. The project entails the supply, erection, operation, and maintenance of a gas turbine at a power and desalination plant. This megaproject includes a number of milestones and key activities and is a fast-track project. The focus of this study is on the key activities that require the study of SC risk management, particularly pipe spool items. These activities are essential for the project and have a significant role in its completion. Process piping was chosen for illustration as it is a common element of most industrial construction projects and is known to suffer from the effects of uncertainty in the supply network. The pipe spool manufacturing and transportation process is illustrated in Figure 4.

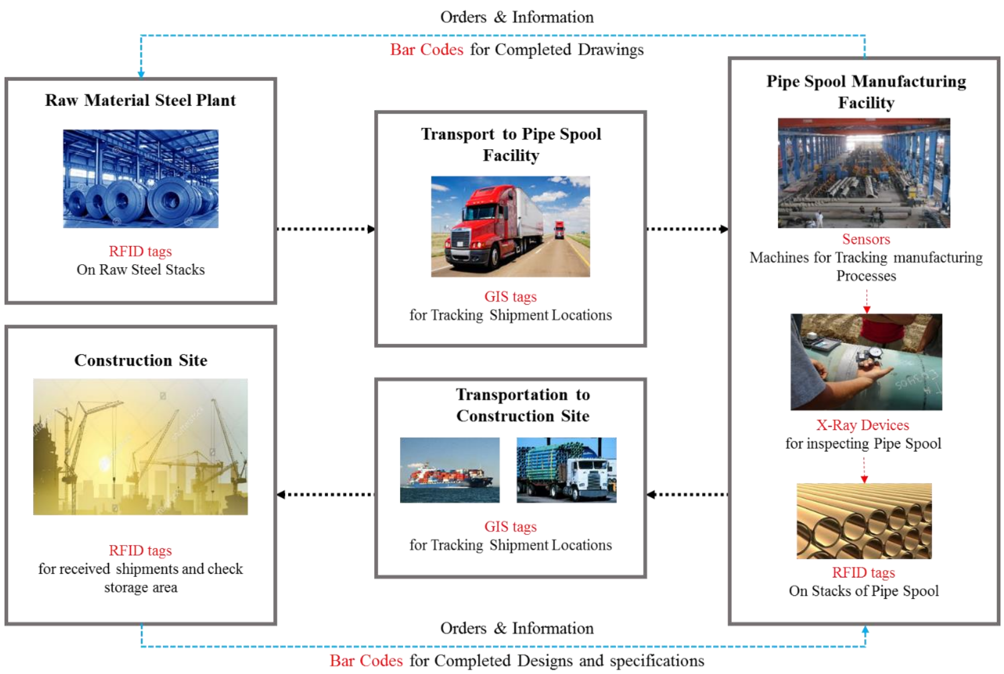

Figure 4: the Pipe Spool Process for the Proposed Model

The case study involves 20 pipe spool activities at different stages in their SC life cycle. The analysis in this paper targets to compare between three supply chain monitoring methods: (1) No SC updates; (2) Typical manual periodic updates; and (3) Supply chain visibility tools. The main factors related to the construction and fabrication phase are shown in Table 1. A detailed risk register was then defined, including individual probability distributions for the risk factors and expected impacts. An initial MC simulation was run with 5000 scenarios, and the experiment was repeated 10 times. The results produced a project duration distribution that ranges between 641 days and 675 days (as opposed to the 620 days deterministic duration without considering risk), as shown in Figure 5.

Table 1: Risk Factors Affecting the Process of Pipe Spools Manufacturing and Transportation

Construction SC Risk Factors (Risk Register)		SC Phase
R_1	Changes in specification	Specifications
R_2	Design Change and Drawing approvals	Design
R_3	Price Change	Procurements
R_4	Subcontractor bankruptcy	Procurements
R_5	Market Condition (interest, exchange)	Procurements
R_6	Late client payment	Procurements
R_7	Early or late deliveries	Const. and Fab.
R_8	Speed of construction	Const. and Fab.
R_9	Bad performance from suppliers	Const. and Fab.
R_{10}	Insufficient Resources	Const. and Fab.
R_{11}	Insufficient Workspace	Const. and Fab.
R_{12}	Insufficient Equipment	Const. and Fab.
R_{13}	Weather Change	Transportation
R_{14}	Environmental Hazards	Transportation
R_{15}	Item Damages	Transportation
R_{16}	Delivery bottlenecks	Transportation
R_{17}	Items Loss	Transportation
R_{18}	Improper Storage	Site Storage
R_{19}	Accessibility to Site	Site Storage

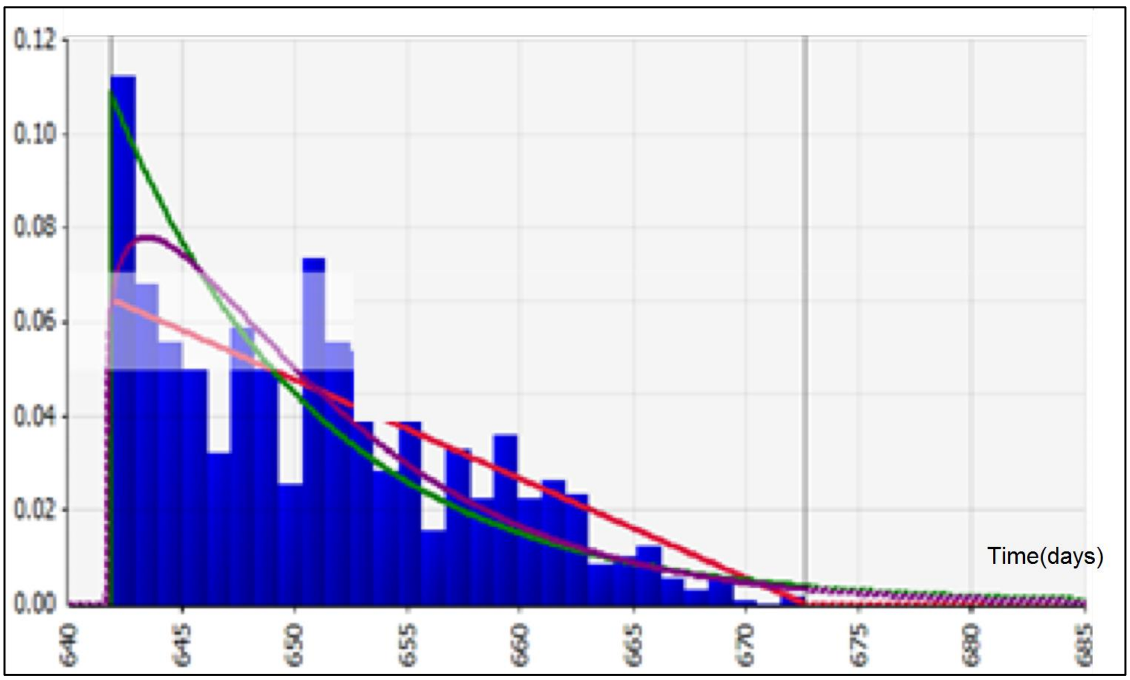

Figure 5: Probability Distribution Function for Duration

Following the above step, frequent risk updates were performed, MC simulation was rerun, and the project duration distribution was updated. The comparison among the three methods of supply chain monitoring is shown in Figure 6. The first curve to the left represents the case of using no supply chain monitoring tools where project duration is underestimated, and the project time distribution is the initial MC simulation results. For this curve, no updates were carried out and the distribution is narrow. The second (middle) curve represents the updated progress based on manual periodical reports. After receiving a specific report, the progress is updated and the completion time is forecasted based on the new information. Since a modest type of update is used (usually late as per the time of receiving monthly reports), the project duration distribution is wider. The third curve represents the use of frequently updated SC data (various individual points that relates to each individual pipe). Accordingly, the MC simulation results show the widest project time distribution since actual progress shows delays and variability. This case study, as such, demonstrates that having the ability to track the actual productivity of any given item will provide better forecasting of project time variability.

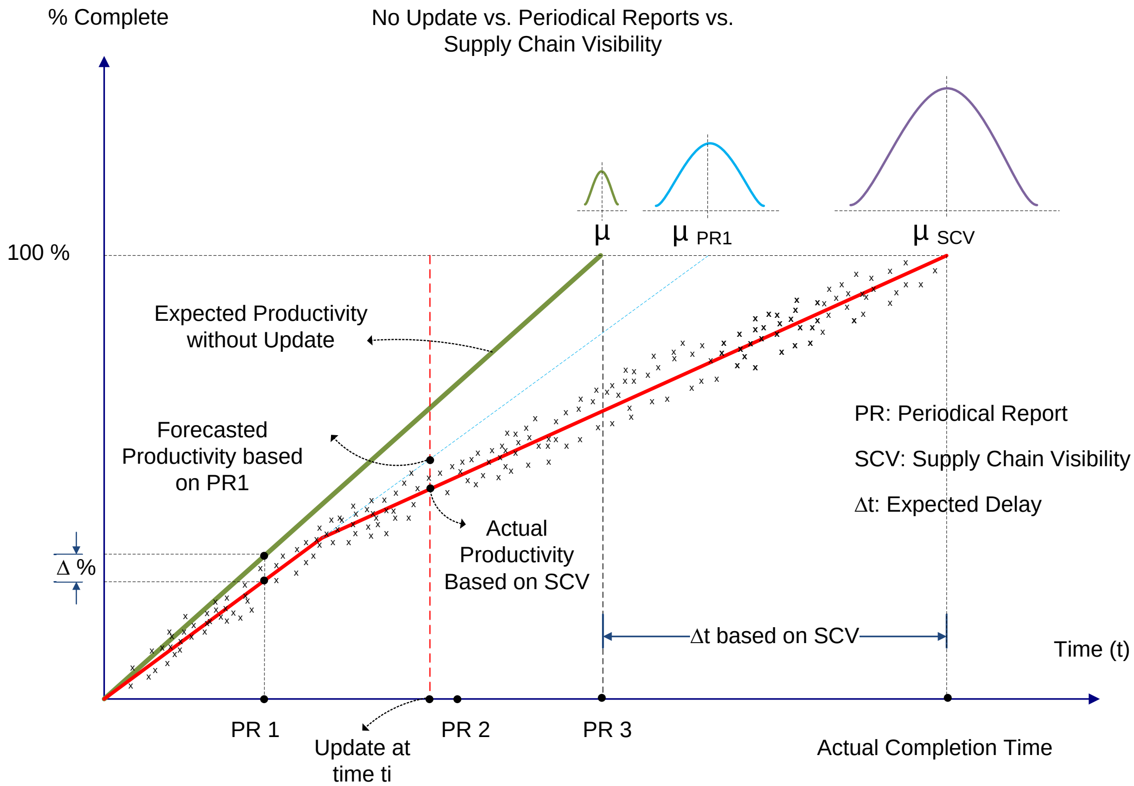

Figure 6: Comparison of Progress with Different Information Levels

4 Conclusion

This paper introduces research effort towards developing a novel model that promptly predicts the influence of major risk factors on the progress of construction projects. The proposed model ensure instant detection for any risk factors take a place during the execution of projects. This paper demonstrated that automated supply chain visibility tools such as RFID tags, GPS tags, Bar Coding, and Machine sensors enable timely and accurate detection of progress delays. The integration of MCS within the proposed framework enables accurate and dynamic assessment of project duration variability. The framework is currently being enhanced to refine the probability distribution for the risk factors and the impact computations. Applying and verifying the system on different practical case studies will then follow.

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References

Christopher, Martin, and Hau Lee. "Mitigating supply chain risk through improved confidence." *International journal of physical distribution & logistics management* 34, no. 5 (2004): 388-396.

Construction Industry Institute. (1999). Procurement and Materials Management: A Guide to Effective Project Execution. University of Texas at Austin. Austin: Construction Industry Institute.

Delen, Dursun, Bill C. Hardgrave, and Ramesh Sharda. "RFID for better supply-chain management through enhanced information visibility." *Production and Operations Management* 16, no. 5 (2007): 613-624.

Hegazy, Tarek, and Wail Menesi. "Enhancing the critical path segments scheduling technique for project control, this paper is one of a selection of papers in this Special Issue on Construction Engineering and Management." *Canadian Journal of Civil Engineering* 39, no. 9 (2012): 968-977.

Jaselskis, Edward J., and Tarek El-Misalami. "Implementing radio frequency identification in the construction process." *Journal of Construction Engineering and Management* 129, no. 6 (2003): 680-688.

Kini, Damodara U. "Materials management: The key to successful project management." *Journal of management in engineering* 15, no. 1 (1999): 30-34.

Kiziltas, Semiha, and Burcu Akinci. "The need for prompt schedule update by utilizing reality capture technologies: A case study." In *Construction Research Congress 2005: Broadening Perspectives*, pp. 1-10. 2005.

Logsdon, T. (1995). Understand the NAVSTAR: GPS, GIS, and IVHS (2nd Edition ed.). New York, NY, U.S.A.: Van Nostrand Reinhold. Futcher, K. _2001_. “User survey on a WAN portfolio MIS used for portfolio/project management in Hong Kong.” Proc., IT in Construction in Africa, CIB W78 Workshop, White River, South Africa, 44-1– 44-14.

Razavi, S. N., Young, D. A., Nasir, H., Haas, C. T., Caldas, C., Goodrum, P., et al. (2008). Field Trial of Automated Material Tracking in Construction. CSCE 2008 Annual Conference. Quebec City.

Song, Jongchul, Carl T. Haas, Carlos Caldas, Esin Ergen, and Burcu Akinci. "Automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects." *Automation in Construction* 15, no. 2 (2006): 166-177.

Thomas, H. Randolph, David R. Riley, and John I. Messner. "Fundamental principles of site material management." *Journal of Construction Engineering and Management* 131, no. 7 (2005): 808-815.