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SCHEDULE RISK ANALYSIS OF RAILWAY PROJECTS USING MONTE CARLO SIMULATION FOR IMPROVED PROJECT MANAGEMENT

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Railways have been used throughout history for the transportation of goods. Even though the inception of rail transport improved civilization, due to its inefficiencies, road transport is at present dominating the freight and logistics industry. Company A, which has the largest market share in the rail freight business, has embarked on projects to improve rail efficiencies by moving higher volumes of freight timeously. Most of the projects embarked on by Company A have failed largely due to the poor planning of the projects in the feasibility stages. Most of the planning schedules are overoptimistic and unrealistic making them unreliable and difficult to track. The scope of this study was to investigate the way in which planning schedules of Company A are developed by undertaking a schedule risk analysis on one of the planning schedules titled 'Design of railway exchange yard' and using Monte Carlo simulation to validate the schedule. If projects of Company A can be planned better, using schedule risk analysis, projects can become more successful and completed within the required time frame.

Keywords: Critical path method, Schedule sensitivity index, PERT.

1 INTRODUCTION

Railways have been of great significance in the progression of civilization and in the transportation industry at large. The inception of the railway improved the efficiency of the logistics and transportation industry as goods were able to be moved from one place to another in higher volumes. Steam-powered locomotives were first developed in 1825 with the first railway line opened for public use in Darlington (Chandra and Agarwal 2013). Modern railways include electrical and diesel-powered locomotives. The use of railways for transportation of goods has grown steadily over time but road transport has had a substantially faster growth rate and has a larger market share in the transportation and logistics industry. The market share of railways in freight business is only between 15-25%, which is low compared to the capital cost of its infrastructure. In 2013, it was documented that for general freight business, road transport accounted for 221 billion tonne-kilometers of freight delivery in South Africa while rail accounted for only 39 million tonne-kilometers (Scott 2007).

A company (Company A) in Southern Africa has the largest market share in the railway industry regarding freight business. Due to the declining growth of railway use in the freight business, Company A has embarked on major projects in the past 5 years with the aim of transferring freight volumes from road to rail. The types of projects that have been implemented by Company A include the following:

- Upgrading track infrastructure to run faster trains and thus increase volumes;
- Purchasing trains that require less maintenance, and thus less downtime of trains;
- Construction of new railway lines to run more routes and thus increase overall volumes;
- Running longer trains to transport higher freight volumes.

The formative planning stages of these projects implemented by Company A have been thoroughly neglected and have resulted in overrunning project schedules leading to late project delivery. Most of the projects overran the budget substantially due to the late completion of the projects. The schedules for the projects are unrealistic and thus projects are not able to realize benefits at the planned dates. The planning schedules do not incorporate risk and uncertainty, which leads to project failure because most deadlines are not met.

The focus of this report was to analyze a planning schedule which was developed by Company A in March 2015 and to use Monte Carlo simulation to validate the activity durations and completion dates. The planning schedule used in this study was titled 'Design of a railway exchange yard' and the Critical Path Method (CPM) was used to develop this schedule. A schedule risk analysis was done on the existing planning schedule (Design of a railway exchange yard) for Company A. Schedule risk analysis is a scheduling technique which is used to determine activity durations of a schedule by incorporating risk and uncertainty and determining whether the completion date estimated is accurate with a certain level of confidence (Tao *et al.* 2017).

2 LITERATURE REVIEW

A schedule or project plan is a major tool, which is used in project management to monitor, manage and control project activities. One of the key factors that determine whether a project is successful is when it is completed on time (Patel *et al.* 2013). A schedule breaks down the deliverables of a project into activities with durations to determine the total duration required to deliver or complete the project. Project schedules are commonly based on a Work Breakdown Structure (WBS) which groups work into manageable portions (PMBOK® 2013). One of the critical project management concepts used as a framework for managing projects, is the project management triple constraint triangle. Quality forms an integral part of the constraint triangle. An extension or restriction of one of the constraints, may impact on the performance of the other constraint and thus that of the entire project (Mokoena *et al.* 2013).

2.1 Monte Carlo Methods

Monte Carlo methods also known as Monte Carlo experiments are a form of computational algorithms that use repeated random sampling to obtain a numerical result. Monte Carlo methods are used to provide approximate solutions in several complex, physical as well as mathematical problems and have formally been used since the 1940s (Walker 2016). Monte Carlo simulation, also known as probability simulation is a mathematical technique, which is used to model risk and uncertainty in a quantitative analysis. Monte Carlo simulation is used widely in project management, statistics, finance, insurance, research and development and in engineering. Simulations were first started in the 1930s by Enrico Fermi and have since gained popularity in modeling different physical and conceptual systems (El-Reedy 2016). Monte Carlo simulations are also used in the validation of project schedules.

2.2 Schedule Risk Analysis

Uncertainty is a very big part of projects and project schedules are no exception. Risks in project schedules reduce the probability that a project will be completed within the specified time. For projects to be completed on time, uncertainty needs to be considered during schedule development. Monte Carlo simulations are a very effective tool in determining the impact of the identified project risks on the project duration and thus form a critical part in schedule risk analysis (Martinelli and Milosevic 2016). Projects sometimes experience technical challenges and schedule risk analysis addresses the probability that the planned completion date will be met with a certain level of confidence and determines the effect of activities slipping onto the schedule's critical path (GAO Cost Estimating and Assessment Guide 2010). The following are the steps followed to perform schedule risk analysis: 1) preparation of project schedule, 2) identification of schedule risk sources, 4) estimation of 3-point activity duration ranges-assignment of probabilities, 5) Monte Carlo simulation.

2.3 Simulation of Schedule

Once the schedule has been prepared and developed using the CPM, risks identified and activity ranges as well as distributions have been determined, Monte Carlo simulation can be run to determine with a certain level of confidence if the estimated completion date is realistic. The purpose of a simulation is to replicate real-life problems using a set of defined assumptions. This method makes it easy to control risk within a project schedule and is also a good decision-making tool (Wang and Huang 2009). The Monte Carlo simulation for schedule risk analysis answers three critical questions in project management and in schedule development namely: 1) Is the completion date of the project, or the duration provided to complete the project realistic? 2) Is the duration provided, the most-likely duration? 3) How much more time can be allocated as contingency to reduce the overrun risk exposure?

3 METHODOLOGY

To perform schedule risk analysis on the 'Design of a railway exchange yard' schedule, the following steps were taken:

- A schedule was prepared using the CPM in Primavera P6 software using the 'Design of a railway exchange yard' specification. Three questionnaires were then developed and distributed together with the schedule once the schedule was completed.
- A questionnaire was conducted using SurveyMonkey to identify the 10 key activities in the schedule with the highest risk source. Two questionnaires were distributed together with the 'Design of a railway exchange yard' specification. The purpose of the specification was to give context to duration estimation.
- Questionnaire 2 was titled: Three-point Estimation. The purpose of this questionnaire was to use the three-point duration estimation technique to estimate activity durations of the 10 activities identified as having the highest risk source in the schedule.
- Questionnaire 3 (Activity Distribution). The purpose was to identify the distribution functions, which would best model each of the 10 risky activities in the schedule.
- Once the three-point duration estimation and distribution had been identified, a Risk Analysis Software and a Monte Carlo simulation was run.
- The output from the Monte Carlo simulation included the following: 1) probability distribution, with the expected completion date, 2) a tornado chart which provided sensitivity of the results.

4 RESULTS AND ANALYSIS OF RESULTS

The activities of 'Design of a railway exchange yard' schedule was developed by the planner of Company A. The schedule commenced on 9 March 2015 and the completion date was 11 October 2016. All relationships were FS (Finish to Start). The questionnaires were distributed to the project team from Company A with the 'Design of railway exchange yard' schedule in order to validate the 'Design of a railway exchange yard' schedule. The sample sizes used for each of the questionnaires can be seen in Table 1. Therefore, the relevant project team selected included: 1) planners of various technical backgrounds, 2) project managers, and 3) design engineers.

Table 1. Sample size for questionnaires 1-3.

	Planners	**Project M/Construction Managers**	**Design Engineers**	**Total**
Q1	10	15	10	35
Q2	10	10	10	30
Q3	15	10	10	35

4.1 Questionnaire 1 (Risky Project Activities)

The purpose of Questionnaire 1 was to identify activities in the schedule that had the highest source of risk according to the project team. All the activities in the 'Design of railway exchange yard' schedule was inputted as part of Questionnaire 1 using SurveyMonkey. As can be seen from Table 2, Perway and Architectural designs are the activities that have the highest risk in the schedule. This might be because these activities are the first to commence and if delayed, they delay the start of other engineering designs such as structural, electrical and mechanical.

Table 2. Results of risky activities selected by project team.

Activities	**%**
Project initiation-business case development	1.86
Procurement of survey	3.18
Procurement of Geotech	3.45
Site survey	*9.02*
Geotechnical fieldwork and report	*11.94*
Perway design	*14.85*
Drainage design	*6.10*
Architectural design	*14.06*
Mechanical design	*6.37*
Structural design	4.77
Health and safety management plan	2.65
Environmental: Water use license	*5.57*
Municipal submissions	*7.96*
Quality management plan	3.98
Risk management plan	3.71

4.2 Questionnaire 2 and 3

The purpose of Questionnaire 2 was to determine the activity durations of the identified risky activities using the three-point estimation. The optimistic, most-likely and pessimistic durations for each activity were provided and the average duration (in weeks) for each activity was calculated. The purpose of Questionnaire 3 was to determine the distribution that best fits the risky activities identified. The project team selected the distributions that best represented the activities and the results were provided in graphs and tables as percentages of the total number of respondents.

4.3 Monte Carlo Simulation Results

To perform a Monte Carlo simulation, the ‘Design of a railway exchange yard’ schedule was inputted into Primavera Risk Analysis Software. As per Questionnaire 1 and Questionnaire 2, the optimistic, most-likely and pessimistic durations were inputted into the software together with the preferred distribution functions. All other activities were inputted with the most-likely duration. 1000 Monte Carlo iterations were performed on the schedule. Table 3 summarizes the risky activities together with durations (In Weeks) as well as distributions.

Table 3. Summary of activity durations (In Weeks) and distributions.

Activities	**Optimistic**	**Most likely**	**Pessimistic**	**Distribution**
Site survey	6	9	12	Beta Pert
Geotechnical fieldwork and report	8	10	14	Beta Pert
Perway design	4	5	8	Triangle
Drainage design	4	5	8	Tringle
Architectural design	6	8	10	Beta Pert
Mechanical design	3	6	8	Triangle
Environmental: Water use license	52	52	52	Uniform
Municipal submissions	17	24	33	Beta Pert

Figure 1 shows the probability distribution for all (frequency histogram) the possible dates that the project can be completed. Using this graph, one can determine with a certain confidence level when the project will be completed. From the graph, the completion date with a 50% confidence level is 7/10/2016. The completion date with an 80% confidence level is 7/11/2016. The completion date with 100% completion level is 14/12/2016. The original completion date of the schedule before simulation was 11/10/2016. This shows that the original schedule was optimistic and unrealistic and did not account for risk and uncertainty.

Figure 2 displays the activities that have the highest risk in the project schedule and thus the activities that have the greatest effect on the overall schedule. The tornado chart is based on the metric Schedule Risk Index (SSI). The following activities have the highest sensitivity and overall highest influence on the schedule: 1) application of water use license 2) geotechnical field work and report 3) procurement of geotechnical studies.

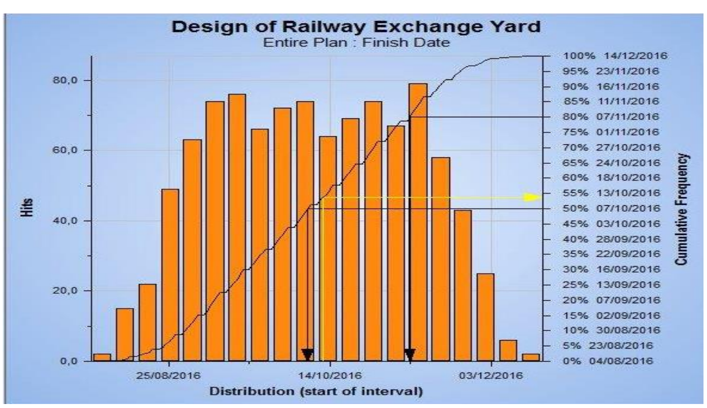

Figure 1. Probability distribution.

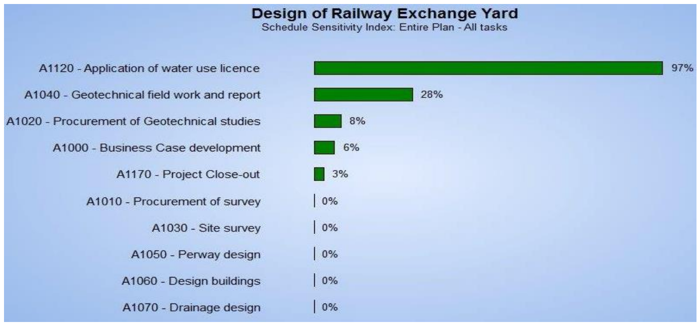

Figure 2. Schedule Sensitivity Index: Entire plan.

5 CONCLUSIONS

This study has illustrated the importance of risk identification in the development of project schedules. The schedule risk analysis performed on the schedule provided guidance as to which activities had the highest risk source and which activities had the potential to delay the entire project. The schedule risk analysis provided a confidence level as to when the project would be completed, which gives the project team comfort. As per the results, the projected completion date based on the Monte Carlo simulation was 14/12/2016, which is two months later than the original estimated date. This proves that the original schedule was overoptimistic and unrealistic. It is recommenced, that Company A uses schedule risk analysis to develop all planning schedules. Schedule risk analysis accounts for risk and uncertainty and once mitigation measures are put in place, the schedule can be managed with ease. Company A will thus be able to plan for the execution of projects at the correct time and benefits can be realized as planned.

References

Chandra, S., and Agarwal, M. M., *Railway Engineering.* (2nd Edition), Oxford: Oxford University Press, 2013.

El-Reedy, M. A., *Project Management in the Oil and Gas Industry*. New Jersey: John Wiley & Sons, 2016.

GAO Cost Estimating and Assessment Guide, *Best Practices for Developing and Managing Capital Program Costs*, (GAO-09-3SP), U.S. Government Accountability Office, 2010.

Martinelli, R. and Milosevic, D., *Project Management Toolbox.* (2nd Edition), New Jersey: John Wiley & Sons, 2016.

Mokoena, T. S., Pretorius, J. H. C., and Wyngaard, C. J. V., *Triple Constraint Considerations in The Management of Construction Projects*. Industrial Engineering and Engineering Management (IEEM), 2013 IEEE International Conference, 2013.

Patel, A., Bosela, P. A., and Delatte, N. J., 1976 Montreal Olympics: Case Study of Project Management Failure, *Journal of Performance of Constructed Facilities*, 27(3), 362-369, 2013.

PMBOK®, *A Guide to the Project Management Body of Knowledge* (PMBOK® Guide), Newtown Square: Project Management Institute, 2013.

Scott, S., *Market Analysis: The South African Transport and Logistics Industry - An Industry in Turmoil*, Cape Town: Smart Procurement, 2007.

Tao, L., Wu, D., Lui, S., and Lambert, J., Schedule Risk Analysis for New-Product Development: The GERT Method Extended by A Characteristic Function. *Reliability Engineering & System Safety*, 167, 464-473, 2017.

Walker, D. J., *Computational Physics - An Introduction. Mercury Learning and Information.* Mercury Learning and Information, 2016.

Wang, X. X., and Huang, J. W., *Risk Analysis of Construction Schedule Based on Monte Carlo Simulation*. Computer Network and Multimedia Technology, CNMT 2009 International Symposium, 2009.