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Total project planning: Integration of task analysis, safety analysis and optimisation techniques

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1. Introduction

The safe and successful completion of maintenance and overhaul procedures is dependent upon the collaboration of different departments and individuals, the clear planning of the work, and the availability of the required resources. For complex or rarely performed procedures, the competence and knowledge needed for planning and mitigating the risks associated with the project may be spread across different parts of the organisation. However, accessing and utilising this knowledge is critical for de-risking major projects and investments. Major projects, for example the delivery of the London Olympic Park, are increasingly placing value on the ability of suppliers and contractors to deliver projects with the highest levels of safety (Shiplee et al., 2011) and the criticality of safe performance of maintenance procedures is illustrated by major accidents such as Piper Alpha, Clapham Rail Disaster, and Texas Oil Refinery. However, Badri et al. (2012) state that project management is often deficient in integrating safety risks. In a study of 183 process industry major accidents, Okoh and Haugen (2014) found that 44% had a link to maintenance and of these, deficient planning/scheduling/fault diagnosis were a cause in 69%. Maintenance is also a factor in 15-20% of all occupational health and

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ABSTRACT

Safe and successful completion of complex projects in industrial environments requires careful planning and collaboration of different stakeholders. This paper presents the integration of three methods (task analysis, safety analysis, and project optimisation) to apply a holistic approach to complex project planning. The attributes and limitations of the separate elements are discussed, and a case study applying the integrated methodology is presented. The results from the case studies indicate that significant benefits in terms of time, cost and safety can be achieved through the application of the integrated methodology. © 2016 Elsevier Ltd. All rights reserved.

safety accidents, and 10–15% of all fatal accidents (OSHA, 2011). The need for safer maintenance must also be balanced with the business requirements for time and cost effective completion of maintenance activities.

Previous research has focussed on identifying safety hazards as part of the project planning process, and has had some success in integrating the safety analysis with 4D models used to communicate and engage with project stakeholders (e.g. Benjaoran and Bhokha, 2010: Gerbec et al., 2016a). This paper extends such work by also incorporating uncertainty modelling using the Monte Carlo technique, giving stakeholders the ability to assess the impact of different resourcing choices on the project timescales and risk. This paper presents a methodology for the elicitation of the information required to fully plan a maintenance activity, assessing both safety and efficiency goals, using a participatory approach that harnesses the existing knowledge in the organisation and engages key stakeholders in planning activities to help ensure safe and timely completion of activities. The results of a case study application of a maintenance overhaul procedure in an electricity generating station are also presented. The approach was developed under the scope of the TOSCA (Total Operations for Safety Critical Activities) project, which developed a set of principles, processes and tools to support Total Safety Management (TSM; Kontogiannis et al., 2016). TOSCA proposes the development of a Common Operational Picture supported by four safety pillars: commitment in action, understanding risks and hazards, managing/treating risks, and





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learning from experience. The methodology presented in this paper contributes to commitment in action, through the use of participatory approaches, and understanding risks and hazards.

The methodology consists of three strands:

- A participatory workshop to produce a detailed task analysis of the works, providing a basis for the plan;
- A participatory risk assessment based on the task analysis, to identify risks and plan appropriate mitigations;
- A Monte Carlo simulation based on the task analysis, to provide a cost-benefit analysis of the use of additional resources.

The participatory approach is designed to engage stakeholders from across the organisation in the planning, and ultimately the successful completion, of the maintenance project. This approach draws strongly on the area of Participatory Ergonomics, an approach concerning "the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals" (Wilson, 1995, p. 1071). Kuorinka (1997) describes the role of all those with firsthand experience of the problem in question to work together towards problem solving, i.e. the participation of stakeholders. The benefits of a participatory approach are improved design solutions incorporating the accumulated knowledge and experience of the stakeholders, and improved acceptance of the solutions (Gyi et al., 2015). Typically, Participatory Ergonomics approaches tackle issues in the everyday operations of an organisation, such as production lines, using a wide variety of methods (Nagamachi, 1995). However, Kuorinka (1997) suggests that complex industrial processes may also benefit from participatory approaches, particularly considering they are typically not well represented by the procedural standards. In terms of safety management, participatory ergonomics approaches have been widely applied with the objective of preventing musculoskeletal disorders (Yazdani et al., 2015) but may also be effective in creating a strong safety culture (Rocha et al., 2015). The participation of the workers in identifying hazards and developing mitigations helps to engage workers in safety, while increasing the realism of the safety assessment and the practicality of the mitigation measures.

The data collection and analysis is based on bottom up estimation techniques (PMI, 2013) captured in a tabular task analysis that is subsequently used as the basis of the risk assessment. Task analysis is the human factors equivalent of a functional analysis in systems engineering, where task analysis identifies and examines the tasks performed by human operators when interacting with the system (Kirwan and Ainsworth, 1992). As in a functional analysis, decomposition of higher-level functions adds more detail and allows system objectives to be allocated to lower-level functions. Task analysis methods are widely used by human factors professionals for a variety of purposes, including risk assessment of human activities and tasks within a system (Kirwan, 1998). Common task analysis representations include Hierarchical Task Analysis (HTA; Annett and Duncan, 1967), Link Analysis (Chapanis, 1996), Operational Sequence Diagrams (Kirwan and Ainsworth, 1992), Cognitive Task Analysis (CTA; Stanton et al., 2005) as well as more general process and flow-chart techniques. The data for these representations are usually captured through observations, analysis of documentation, and/or interviews. Tabular task analysis captures the data in a sequential list of tasks, broken down into sub-tasks as necessary.

The completed task analysis can be used to structure a risk assessment, where hazards can be identified and analysed for each task documented in the task analysis. Hazard identification is based on screening issues according to five types (offering prompts specific for the domain) to identify possible issues connected with

each step of the task analysis using a structured workshop format. This approach is similar to a HAZOP study (Kletz, 2006) in which each part of a plant is examined in turn, but in this approach the nodes are individual (sub)tasks instead of parts of a plant. The approach can be referred to as Task HAZID (Leva et al., 2012; Demichela et al., 2014; Gerbec et al., 2016a). The identification of hazards can be accompanied with a semi-quantitative risk category estimation in order to separate between safety and productivity issues. This involves assigning the consequence classes on a scale (e.g. 1-5), and similarly assigning their likelihood of occurrence, while risk values are simply provided by multiplying both. The method allows the hazards associated with each task to be identified in the form of possible deviations from the correct execution of the task. The consequences and likelihood of each deviation is explored, and finally mitigations identified where appropriate.

Finally, a Monte Carlo optimisation based on discrete event simulation can be used to examine the possible impact of different resource configurations. Discrete-event simulation models a process as a discrete sequence of well-defined events in time. Such events occur at a particular instance in time, marking a state change in the process (Robinson, 2004). Discrete-event processes must include predetermined starting and ending points, and a list of discrete events that occur in between these points. The task analysis is ideally suited to providing these points. Discrete-event simulation is commonly used to monitor or predict procedures and processes in various industries, such as manufacturing. The final aim of a simulation is to define a precise scheduling of the listed tasks, considering all known external and internal constraints characterizing the whole activity to be organized. In order to provide a highly reliable plan of the tasks, the simulation should take into account a number of variables to consistently adhere to reality. Uncertainties may be generated from the inability to precisely predict the duration of each task due to external constraints, lack of knowledge, and the possibility of known or unknown issues arising during the project. The participatory approach helps to elicit as much information as possible about the task sequence. expected durations, and possible issues (including safety concerns) and thereby reduce the uncertainty. Especially when the activity is characterized by high level of internal and/or external constraints, it is of extreme importance to include the uncertainty affecting the hypothesis used to introduce those constraints in the simulation. In the present case study, the main constraints refer to the mutual conditioning of some subtasks (i.e. one task cannot be performed unless another one is already complete), availability of resources (e.g. people and tools) and the time of some external events necessary for accomplishing the procedure in safe conditions (i.e. time of tides). In this sense, Monte Carlo (MC) method has been identified as a suitable tool to run a discrete-event simulation under uncertainty since it allows the computation of a mean value and a variance of the given quantity under investigation. This quantity is governed by a known phenomenon depending on a set of variables characterized by a level of uncertainty (i.e. the input variables are introduced as a set of mean values and a related variances or in form of Probability Density Function, instead of a set of definite values). MC computes a set of estimations of the final quantity based on different values of input variables generated according their Probability Density Function. Consequently, the final output of the simulation will be an average of the quantity under investigation and a related variance depending on the variance of the input variables. In this specific case, the exploitation of MC is very advantageous for estimating the final planning of an activity taking into account the uncertainty declared by the stakeholders about the duration of each task. Indeed, the application of the Monte Carlo optimisation gives a more nuanced result from the analysis than is possible through the task and safety analysis. It allows dif-

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