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Simulation-based evaluation of an integrated planning and scheduling algorithm for maintenance projects

Rohit Patil
University of Wollongong

Nagesh Shukla
University of Wollongong, nshukla@uow.edu.au

Senevi Kiridena
University of Wollongong, skiriden@uow.edu.au

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Abstract

The field of maintenance project planning and scheduling is attracting increasing attention due to ever growing competition among manufacturing organisations. There is a lack of studies that has tackled all the aspects of maintenance project implementation such as costs, resources, down times, uncertainties, operational constraints, among others. Therefore, an approach which uses a unitary structuring method and discrete event simulation to integrate relevant data about the maintenance projects is proposed. The results of the evaluation, on a case from paper-pulp industry, have shown that the proposed approach is able to overcome most of the issues of maintenance planning and scheduling.

Keywords

scheduling, projects, maintenance, algorithm, simulation, evaluation, planning, integrated

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Rohit Patil
School of Mechanical, Materials and Mechatronic Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, NSW 2522, Australia

Nagesh Shukla (Email: nshukla@uow.edu.au)
SMART Infrastructure Facility, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, NSW 2522, Australia

Senevi Kiridena
School of Mechanical, Materials and Mechatronic Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, NSW 2522, Australia

Abstract:
The field of maintenance project planning and scheduling is attracting increasing attention due to ever growing competition among manufacturing organisations. There is a lack of studies that has tackled all the aspects of maintenance project implementation such as costs, resources, down times, uncertainties, operational constraints, among others. Therefore, an approach which uses a unitary structuring method and discrete event simulation to integrate relevant data about the maintenance projects is proposed. The results of the evaluation, on a case from paper-pulp industry, have shown that the proposed approach is able to overcome most of the issues of maintenance planning and scheduling.

Key words: planned maintenance; planning and scheduling; project implementation

Topics: reliability and maintenance; empirical modelling and simulation; project management

Introduction

Successful completion of planned maintenance projects is critical to achieving the overall performance goals of an organisation which involves cost, time and service level trade-offs from the both strategic and operational perspectives. Such projects also face significant challenges in terms of dealing with resources constraints, accounting for contingencies (uncertainty) and completion of requisite tasks within tight time windows. There has been substantial research undertaken into the planning and scheduling of maintenance operations at the functional level and there is a large array of algorithms currently available for optimising maintenance operations at the upper echelons of the planning hierarchy (Sharma and Yadava, 2011; Garg and Deshmukh, 2006; Dekker, 1996). Compared to the efforts gone into the above research, and despite the challenges associated with project implementation, the work undertaken in the area of planning and scheduling of planned maintenance projects is very limited. Therefore, there is a heightened need for the development of suitable tools to deal with the challenges associated with the implementation of maintenance projects. To this end, this paper evaluates an integrated planning and scheduling algorithm that has the potential to solve the above problem taking into account the both time and constraints, as well as the contingencies arising out of inspections carried out during project implementation.

Literature Review

The focus of maintenance planning research has traditionally been on the development of appropriate maintenance policies or the selection of most effective maintenance strategies considering such factors as plant or equipment condition, reliability and criticality (Ul-Turki, 2009). As such, numerous optimisation models have been developed to prioritise maintenance efforts with respect to achieving the broader strategic organisational goals such as the minimisation of life cycle costs and the maintenance of service levels (Sharma and Yadava, 2011). Another approach that has drawn researcher attention with regard to prioritising maintenance efforts at this level is risk-based maintenance. Risk-based maintenance aims to mitigate the likelihood of system failure and the impact of consequences by taking a systematic approach to managing risk; i.e. identifying, assessing and developing appropriate mitigation measures (Maiti, 2007; Khan, 2003). There have also been a significant body of research focusing on the optimisation of maintenance operations at the next tier of the planning hierarchy; for example, by integrating maintenance planning with production scheduling and quality management for the purpose of improving on overall costs or minimising the losses due to unplanned downtime (Hadidi et al., 2012; Pandey et al. 2011; Aghezzaf et al. 2007). A wide array of models, methodologies and tools covering the above areas are currently available in literature; they include mathematical optimisation techniques (Kuschel and Bock, 2016; Bajestani et al., 2014; Boland et al., 2013; Wang and Liu, 2013; Fitouhi and Nourelfath, 2012; Safaei et al., 2012), simulation approaches (Alrabghi and Tiwari, 2015; Remenyi and Staudacher, 2014) and risk management tools (Maiti, 2007; Sortrakul, 2005; Khan and Haddara., 2003).

Compared to the extent of work undertaken in the above areas, the attention paid to maintenance project implementation has so far been minimal. Planning and scheduling of planned maintenance projects involves first determining the activities to be performed along with the requirements for resources and materials in advance and then allocating the requisite tasks against specific time windows while considering capacity loading on resources (Duffuaa and Raouf, 2015; Ul-Turki, Dekker, 1996). Although the aim of planning and scheduling is to minimise the unplanned work, there is still a high degree of uncertainty involved at this level, largely due the additional work detected during inspection and the lack of availability of spare parts or resources to carry out the work (Erderame et al., 2010). The tools and techniques available in literature to deal with such challenges are limited in many ways, as brought out in the discussion below.

The existing approaches to planning and scheduling of maintenance projects rely on generic tools such as the critical path method, performance evaluation and review technique, Gantt charts and resources levelling available within the standard software packages. As reported by Samaranayake and colleagues (2012; 2002) attempts made to address the limitations of the tools available within the current enterprise resource planning systems has also been faced with challenges around data integration at the lower levels of activities, resources and materials. When used in stand-alone mode or even in interfaced environments, these tools are not capable of dealing with the complications arising out of the interplay among the multiple activities, resources and materials involved or the contingencies associated with the additional maintenance tasks detected during inspections (Samaranayake and Kiridena, 2007). For example, the current ERP systems lack the functionalities needed for simultaneous planning and dynamic forward planning of multiple maintenance operations, or finite capacity loading of resources, primarily because of their technical and design constraints, including lack of integrated data structures (Samaranayake and Kiridena, 2012).The consequent manual interventions performed to address these issues often result in sub-optimal performance outcomes.

The algorithm, known as the 'unitary structuring technique', was initially developed by Woxvold (1993) integrating three existing techniques, namely, critical path method (CPM), hierarchical bill of materials (BOM) structure and production activity control (PAC) rules. Since then, it has been further refined and expanded with contributions of several other authors (Samaranayake and Kiridena, 2012; Samaranayake and Toncich, 2007; Samaranayake et al., 2002). The potential of this algorithm for simultaneous and dynamic forward planning of operations, including finite-capacity loading of resources, has been demonstrated using numerical examples drawn from such diverse application domains as aircraft maintenance, supply chain management and healthcare service delivery (Samaranayake et al., 2015; Samaranayake and Kiridena, 2012; Samaranayake and Toncich, 2007; Samaranayake, 2005; Samaranayake et al., 2002). However, it has not yet been subject to rigorous empirical testing. Therefore, this paper undertakes to evaluate the functionalities of this algorithm using an empirical simulation modelling approach, as the first step towards implementing it in an enterprise system environment.

Methodological approach

The methodological approach used in the validation of the unitary structure model relied on a test case drawn from the paper and pulp industry in Australia (see Appendix 1) and it involved the following steps.

a) Building a set of simulation models based on the proposed integrated algorithm representing a test case ;
b) Running the simulation models using data drawn from the case company;
c) Analysing the simulation results of Step (b) and making comparisons against the current practice of the case company; and
d) Drawing conclusions on the efficacy of the integrated algorithm.

The simulation models were built using the discrete event simulation modelling software Flexsim. The identity of the company involved is withheld due to reasons pertaining to the potential commercial sensitivity of the information presented.

Results and discussion

The unitary structure-based algorithm developed (see Appendix 2) for the implementation of the planned maintenance program associated with the selected plant area is provided in Appendix 1. With a view to providing some context for the problem studied the functional block diagram representing the chosen test case is provided in

Appendix 2. Furthermore, for the purpose of providing a complete account of the procedure followed, as well as for illustration purposes, the results are analysed under four scenarios. It is assumed that same labour resource is utilised for the both planned and unplanned activities in the baseline plan, as well as in the plan generated using the proposed integrated algorithm. The four scenarios that were developed and compared against the baseline plan are presented below.

I. Planned maintenance program developed by the case company and assuming all materials (e.g. spare parts, consumable and other supplies) are available on site. There are no other changes in the baseline plane and no unplanned work is generated from the inspection performed during the shutdown.

II. Inspections detect two additional items to be attended to and one task taking longer than initially estimated, assuming all materials are available on site. In this scenario, the contingencies (shown in Table 1) have been simulated are based on the historical log of maintenance actions that undertook at the company during the execution of a recent planned maintenance project For this test case, it is assumed that all the materials required for unplanned maintenance activities are available on site.

Table 1. Scenario II contingencies for the baseline plan

S.No.	Problem	Solution	Delay caused at task	Activity Delay (Minutes)	Material Delay (Minutes)
1	Inspection of T122 required more time for cleaning	Clean Tank	D58	120	0
2	Inspection of TPFP generated unplanned activity to replace Gasket	Replace Gasket	R109	90	0
3	Inspection at PM6 Pressure Screen generated unplanned activity to replace Bearing Assembly	Replace Bearing Assembly	R110	60	0

III. In this test scenario, the same contingencies are considered as in scenario II but with added delays in material availability (procured as per lead times identified). For planned activities, material is available in store. For the additional/unplanned activities needed to rectify equipment defects, the material is not available in the store and is procured upon the requirements generated from equipment inspections during the shutdown. It is assumed that once a requirement is identified, it takes a total of five hours for the material to be available to begin the unplanned maintenance activity. It is also assumed that these five hours include the time of order placement, receiving of the material, having it available in the warehouse and finally having it available at the location where it is required by the particular maintenance activity. The material delay time shown is the time at which the material requirement was detected after inspection, plus five hours.

Table 2. Scenario III contingencies for the baseline plan

S.No.	Problem	Solution	Delay caused at task	Activity Delay (Minutes)	Required Material ID	Material Delay (Minutes)
1	Inspection of T122 required more time for cleaning	Clean Tank	D58	120	-	0
2	Inspection of TPFP generated unplanned activity to replace Gasket	Replace Gasket	R109	90	GK1T	481.05
3	Inspection at PM6 Pressure Screen generated unplanned activity to replace Bearing Assembly	Replace Bearing Assembly	R110	60	BA2	585.44

IV. This scenario considers the same situation as in scenario (III) plus the situation where required materials not being delivered on time. In this scenario, additional contingencies for unplanned activities due to inspection during the shutdown and the respective material delays are taken into account. A material delay of 5 hours after inspection has been considered for all the unplanned material requirements. Table 3 below shows the simulated contingencies with the material delays. It is further assumed that cleaning of Tank T122 does not require any material to be procured externally.

Table 31. Scenario IV contingencies for the baseline plan

S.No.	Problem	Solution	Delay caused at task	Activity Delay (Minutes)	Material Delay (Minutes)
1	Inspection of T122 required more time for cleaning	Clean Tank	D58	120	0
2	Inspection of TPFP generated unplanned activity to replace Gasket	Replace Gasket	R109	90	481.03
3	Inspection of BPFP generated unplanned activity to replace Gasket	Replace Gasket	R111	90	481.03
4	Inspection at PM6 Pressure Screen generated unplanned activity to replace Bearing Assembly	Replace Bearing Assembly	R110	60	585.58
5	Inspection at PM6 Pressure Screen generated unplanned activity to replace rotor Packing Ring	Replace Packing Ring	R110	60	585.58
6	Inspection of Basis Weight Valve generated unplanned activity to replace the Actuator	Replace Actuator	D112	60	811.5
7	Inspection of Basis Weight Valve generated unplanned activity to replace the Basis Weight Valve	Replace Basis Weight Valve	D112	90	811.5

The project completion times under the four scenarios simulated (I – IV) with reference to the baseline plan, which is the current practice, are provided in Table 4.

Table 4. Summary results: project completion times for simulated scenarios

Scenarios simulated		**I**	**II**	**III**	**IV**
Project completion time (Minutes)	Baseline plan	515.66	585.59	781.59	961.96
	Plan based on Integrated algorithm	515.80	575.90	750.94	841.68
Savings in completion time (minutes)		~ 0	9.69	30.65	120.28

It is observed from the results of the comparison that in Scenario II the proposed plan is completed 9.69 minutes faster than the baseline plan. This demonstrates that the Bill of Material (BOM) hierarchy process included in the unitary structure can help in efficiently completing the possible maintenance tasks associated with replacement of parts identified upon inspection of major assemblies.

Scenario III has taken material unavailability into consideration. The results of the proposed plan show that due to the merged functionalities of Material Requirements Plan (MRP) and Production Activity Control (PAC), the MRP benefited by having more realistic estimates of lead times to procure the unavailable materials. The materials were made available early in the proposed plan compared to the baseline plan (saving 30.65 minutes).

Scenario IV demonstrates increased efficiency in the completion times compared to the baseline plan. Scenario IV was subject to additional unplanned work based on equipment maintenance history and their associated material unavailability. Under the same assumptions, the proposed plan had executed the maintenance project 2 hours (approx.) earlier than the baseline plan. This reduction in completion time has also helped in reducing the maintenance operating costs and thereby improving the efficiency by 12.5%. The improvement in execution time for the shutdown is crucial for the company, because it reduces the downtime associated with the maintenance of the manufacturing unit. The result could allow for an increase in plant's manufacturing productivity with the increase in plant availability.

The results also demonstrate that the critical path for the plan can be altered due to the additional activities detected during inspections. It depends both on the activity durations as well as material availability. Thus, the proposed unitary structure provides accurate completion times; which can lead to maintenance project execution cost and time savings. This is primarily due to the capacity of the integrated algorithm to better deal with the effects of the changes to critical paths that result from the incorporation of additional activities detected during inspections.

This study applied the proposed integrated approach for maintenance planning and scheduling of a small unit (Approach Flow) of the entire paper manufacturing plant. Based on the results, it is anticipated that if the same approach is extended to the entire plant, greater benefits/efficiencies through the simultaneous planning of activities, materials and resources could be achieved.

Conclusions

The aim of planning and scheduling of maintenance projects is to minimise the impact of contingencies that arise during the implementation phase. However, despite the best efforts to achieving this goal, the very nature of maintenance projects brings about situations such as detection of new tasks and unavailability of spare parts or resources. This means, the successful completion of planned maintenance projects depends on an organisation's capacity to develop an accurate and comprehensive schedule of activities, materials and resources, and then dynamically responding to any contingencies that arise during the project execution phase. In this regard, this paper demonstrated the efficacy of an integrated algorithm against the tools used in current practice. However, the industry test case used in this paper only represented a small plant area and the analysis was limited to several selected scenarios. Therefore, the paper does not necessarily provide substantial empirical evidence to conclusively establish the superiority of the proposed algorithm. As such, future simulation efforts could account for variations in resources availability, for example, the utilisation of in-house labour vs. contracted labour, and relax as many assumptions as possible. It could then be empirically validated using a full-scale implementation in a real-world context. Nevertheless, to derive the full benefits, this algorithm should be implemented on a suitable software platform in which data elements relating to all components of the extended unitary structure can also be integrated holistically.

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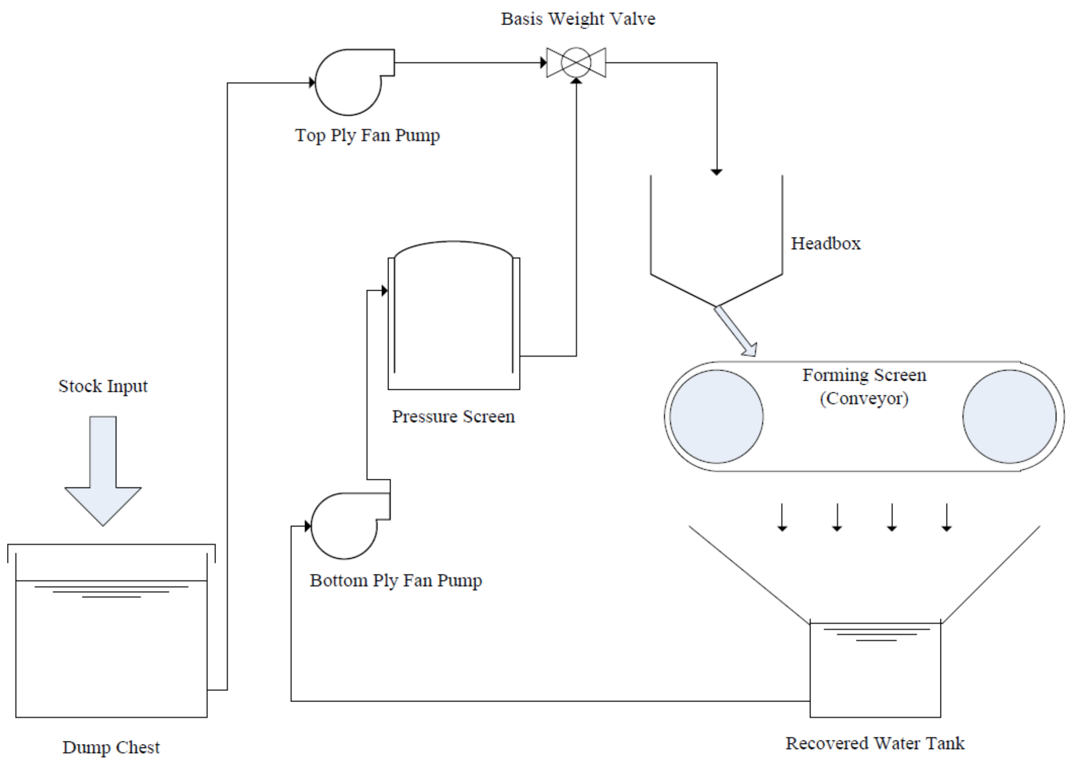
Appendix 1: Functional block diagram representing the industry test case used



Appendix 2: Representation of the Integrated Planning and Scheduling Algorithm (using unitary structuring technique formalism)