A Dynamic Heuristic Optimization for Condition-based Maintenance Planning

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1 Introduction

For mission critical infrastructures (e.g., nuclear, railways and defense), an important issue is how to reduce maintenance costs and manage business risks while increasing the reliability, availability and safety of the assets [1]. For this purpose, Condition-based Maintenance (CBM) of which predictive maintenance (PdM) is a special case [2], is analogously and often used along with the Prognostics and Health Management (PHM). PHM methodologies are increasingly used to improve the maintainability of the operating systems and preparedness of the maintenance organization [2]. PHM can aid to define the optimum time for maintenance intervention, to maximize the use of the assets and plan the maintenance actions at correct times [1, 2]. PHM provides useful probabilistic indicators such as asset performance/degradation trend, health state severity, and Remaining Useful Life (RUL) of the systems and the overall system/asset performance state. With these PHM indicators, organizations can get better idea about overall performance of their systems to make better decisions on planning maintenance operations [2]. However, for any maintenance planning to succeed on time, the planning itself needs to be efficient, keeping into account the constraints of the deadlines (e.g., RUL) and available resources (e.g., logistics, human resources, spares, weather conditions etc.). This translates the problem into the well known Resource-Constrained Project Scheduling Problem (RCPSP) [3, 4].

RCPSP, deals with the scheduling of planned activities (also called as tasks) under constraints of logical relationship among various tasks (e.g., precedence constraints) and availability of resources. RCPSP can be considered to have three main entities : the project itself, the tasks to be accomplished, the resources that can be utilized for the tasks. In addition, in industrial projects (such as maintenance planning operations), there are additional constraints (in terms of security protocols, strict timing of tasks, milestones, etc.) that make each project plan unique in nature.

In this paper, we propose a novel priority-rule based approach for solving the RCPSP of maintenance planning.

2 Proposed approach : Cost Function based Priority Rule

RCPSP is a combinatorial optimization problem which is NP-hard in nature [3, 4]. The RCPSP can be formulated as a project J, with $n+2$ set of tasks, $J = \{0, 1, ..., n, n+1\}$, where 0 and $n+1$ are dummy tasks that represent start/end of the project. Let G be the precedence graph of all tasks. There are total $K = \{1, 2, ..K\}$ resources, with R_k quantity of each resource k. A task j can be executed by using $r_{j,k}$ units of resource type k for a duration d_j. The proposed approach is based on the RCPSP list-scheduling algorithms to perform a simulation with a given time-step t_s to score all the unscheduled tasks of J at each $t+t_s$ using the cost function below. The aim is to give higher score to tasks that are more critical, based on the PHM indicators and the maintenance planning. The score $cost(j,t)$ of a task j at time t is computed as follows :

$$cost(j,t) = 6(\mathbb{1}_{constraints}) + \frac{1}{1+delay_j^+} + pr_j + \mathbb{1}_{constraints} \cdot \left(5(2 - \frac{1}{1+delay^- \cdot pr_j} - \frac{1}{1+RUL^-_{j,c_1} \cdot pr_j}) + \frac{pr_j}{1+RUL^+_{j,c_1}}\right),$$

where $\mathbb{1}_{constraints} = \mathbb{1}_{\{p_{j,t}-p_j=0\}} \cdot \mathbb{1}_{\{r_j \leq R_{ev_j}\}}$ is an indicator function (i.e., 1 if true, else 0) for satisfaction of both the precedence and necessary resource availability constraints for a task at t. Also, $p_{j,t}$ is the number of tasks in the precedence list of j that have been scheduled until t, p_j is the initial number of tasks in the precedence list of j. For resources, r_j is the vector of the quantities of the resources required by j, R_{ev_j} is the vector of quantities available, pr_j is the user-defined priority of j. The factors $delay_j^+, delay_j^-$ are the positive, and negative margins respectively, to the deadline of the task if it was started at t while including its duration. Similarly, $RUL^+_{j,c_1}, RUL^-_{j,c_1}$ are the positive and negative margins respectively, as defined by the RUL indicator provided by PHM and the task j belongs to the maintenance operation for the critical component c_1 of a system.

The advantage of this approach for the maintenance planning practitioners is that with the dynamically changing CBM/PHM provided indicators (e.g., RUL as here), the simulation can be relaunched by changing the inputs hypothesis and also the (weights) of the main factors within the cost function above as per the goals of the maintenance operations.

For each RUL of critical components, their respective deadlines can be considered as a specific milestone for overall maintenance planning project.

3 Conclusion

The above mentioned heuristic approach is novel in its approach of providing a flexible way to weigh different factors involved in order to generate new schedules as per the indicators provided by the PHM/CBM. The extension of this paper will present different use cases from nuclear industries and railways showing that the combination of PHM and RCPSP approaches is defining disruptive approach for engineering maintenance. The outcomes will at time, schedule, dependability and efficiency of the overall systems.

Références

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