International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol. 3, Issue. 4, Jul - Aug. 2013 pp-2183-2186 ISSN: 2249-6645

Worker Scheduling for Maintenance Modeling Software

Samuel C. Littlejohn[1]
*(Department of Industrial and Electrical Engineering Technology, South Carolina State University, United States of America)

ABSTRACT: *This article presents a brief discussion about the scheduling issues related to a maintenance modeling simulation software called, Improved Performance Research Integration Tool (IMPRINT). One of the areas of use for IMPRINT is for maintenance systems. A concise description of IMPRINT is presented. A description of possible application environments for use by IMPRINT is given. The discussions center on maintenance modeling and scheduling because these are primary applications for IMPRINT utilization.*

Keywords: *Maintenance, Scheduling, Maintenance Scheduling, Personnel Scheduling*

I. INTRODUCTION

In general, maintenance systems are created for the purpose of ensuring the serviceability and safety of equipment or systems so that maximum possible performance levels can be achieved. Scheduling and planning are two vital functions of the maintenance modeling paradigm. Scheduling is the arrangement of resources to be used. Planning is the act of ensuring that resources and tools are in order before the required tasks are to take place.

Within the construct of maintenance planning and scheduling, there are two categories. Category one consists of preventive maintenance, routine maintenance, and scheduled overhauls. Category two consists of unscheduled maintenance due to emergencies. Any maintenance schedule should consider both known and unknown circumstances. The primary objective of this research effort is to determine a possible scheduling approach for maintenance models of IMPRINT. IMPRINT is an acronym for Improved Performance Research Integration Tool.

II. IMPRINT OVERVIEW

IMPRINT is a simulation tool that can be used to perform maintenance modeling and analysis. IMPRINT maintenance models calculate the required manpower (number of maintenance workers needed to perform any desired task(s)). In this section, we present a brief overview of IMPRINT.

IMPRINT is a Microsoft Windows® based human performance modeling environment that has been developed by the Army Research Laboratory [1]. It is a stochastic network modeling tool that is designed to help assess the interaction of soldier and system performance throughout the system life cycle. The design originated from previous field testing and system upgrades.

IMPRINT is a simulation tool that is used for three primary reasons. Its first use is for the purpose of helping to set realistic system requirements. It is also used in order to identify soldier-driven constraints on system design. IMPRINT also has the ability to evaluate the potential of available manpower and personnel to effectively operate and maintain a system under given environmental stressors. In a strictly military context, IMPRINT can be used to target soldier performance concerns in system acquisition. IMPRINT is also used to estimate soldier-centered requirements early in the decision process. Another implementation of IMPRINT is as a simulation tool. It incorporates task analysis, workload modeling, performance shaping functions, degradation functions, stressors, and embedded personnel characteristics data. IMPRINT is used to facilitate a number of human factors analyses such as manpower projection, performance under environmental stress, and maintenance under manpower requirements[1].

Micro Saint® is the operating engine that is used by IMPRINT. Micro Saint is an embedded discrete event task network modeling language. The simulation employs task-level information to construct networks that represent the flow, performance time, and accuracy of a given system for operational and maintenance missions. The military uses IMPRINT to model both crew and individual soldier performance. In some instances, IMPRINT utilizes workload profiles that are generated so that crew-workload distribution and soldier-system task allocation can be examined. Other simulation applications may involve a maintainer (i.e., the actual maintenance worker) workload being assessed along with the resulting system availability. Furthermore, by using embedded algorithms, IMPRINT can model the effects of personnel characteristics, training frequency, and environmental stressors on overall system performance. Manpower requirement estimates can be generated for a single system, a unit, or Army-wide. IMPRINT outputs can be used as the basis for estimating manpower lifecycle costs[1].

III. IMPRINT MAINTENANCE MODELS

IMPRINT has maintenance modeling capabilities to predict manpower requirements: reliability, availability, and maintainability (system RAM). This is done by simulating the maintenance requirements of a unit as systems are at different stages. The first stage of a mission is the initiation stage, or the time at which the system operators are sent out. The next mission stage is where any required maintenance is performed. The final mission stage is after maintenance has occurred and the system is finally sent back into a pool of available systems.

When a particular system comes into maintenance, IMPRINT prioritizes and schedules repair based on the pools of maintainers with specialties available in the particular maintenance level that is required. There are other issues that affect the maintenance system such as spare availability, combat damage, maintenance shifting, and the criticality of individual system component failures.

There are certain limitations in the system RAM analysis capability that will affect the results of the program. First, the model assumes that all unit level (or first level) maintenance is performed "on equipment." This means the system will not be considered "available" to be sent out on any other mission until all unit level maintenance is completed. Second and third level maintenance (referred to as direct support (DS) and general support (GS)) are assumed to be performed "off equipment." In other words, the system is considered available before the repairs are complete because it is modeling maintenance as if the failed component has been removed from the system for repair. The model also assumes that maintenance is prioritized so that the system with the smallest amount of total repair time is repaired first. This is commonly referred to as shortest processing time (SPT) scheduling. All unit level maintenance must be completed before any DS level maintenance can begin. In the same way, all DS level maintenance must be completed before any GS level maintenance can begin.

IMPRINT's maintenance model is considered very high fidelity. A key aspect of the system RAM analysis capability is the concept of failure clocks. Each component of each system in the analysis has its own failure clock. The failure clock is used to provide a realistic estimation of component failures, and thus system maintenance requirements, throughout a particular scenario. The next sections discuss possible application environments for use by IMPRINT. The discussions center on maintenance modeling and scheduling because these are primary applications for IMPRINT utilization.

IV. MAINTENANCE MODELING

Under the umbrella of reliability and maintainability, [2] identifies maintenance planning and maintenance scheduling as areas that are directly related to this purpose. According to [2], these are the two most important elements of the maintenance function. They are a requirement for any effective maintenance control. Fig.1 shows a simple schematic breakdown of these two areas in maintenance modeling.

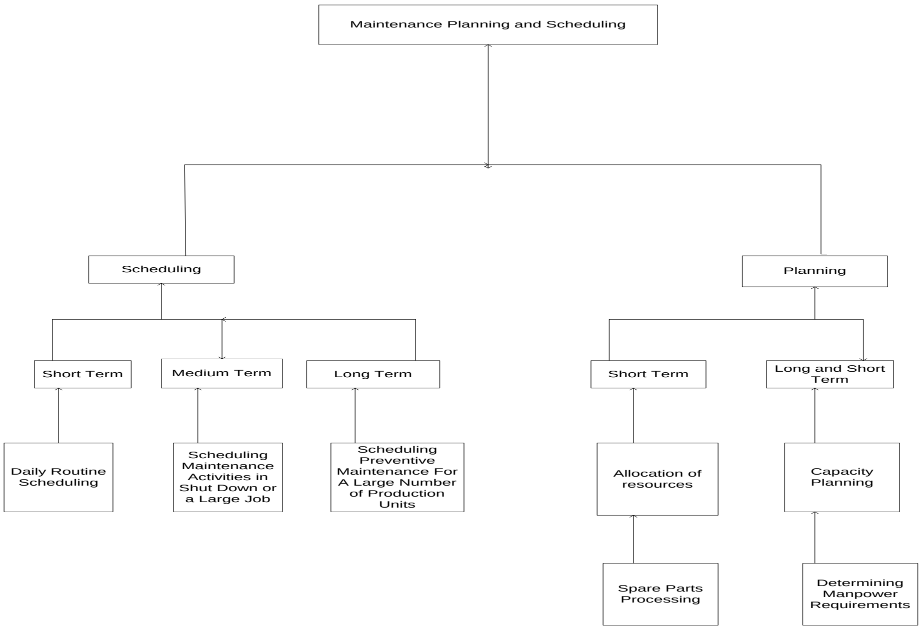

Figure 1: an overview of maintenance planning and scheduling areas [2]

There are three categories of maintenance requirements: manpower, material, and equipment. The most costly of these three categories is manpower. Human resources tend to have high variability when compared to material and equipment. By varying the usage of human resources, maintenance managers are able to have significant control over maintenance scheduling.

Reliability and maintenance are closely related. High quality maintenance corresponds directly to high reliability for any given piece of equipment. Complex maintenance equipment can account for a significant portion of costs associated with a particular piece of equipment. [3] Estimates that military maintenance costs encompass almost one-third of all incurred operating costs.

Three of the most common terms that are used are mean time between failures (MTBF), mean time to repair (MTTR), and availability. MTBF corresponds to the expected time between failures and MTTR represents the expected value of the time it takes to repair a piece of equipment. Availability is the average fraction of time the equipment operates.

Availability can be defined in terms of MTTR and MTBF:

(1) Availability $= \frac{MTBF}{MTBF + MTTR}$

For any operating equipment that exhibits an exponential failure behavior, it can be beneficial to replace the equipment even before it fails. This is especially important in situations in which the cost of replacing a piece of equipment before it fails is much less than the cost of having to replace a piece of equipment if it fails during operation. Because of associated costs, there are some military equipment that are replaced rather than repaired before they get to a point where they completely fail during operation. Therefore this equipment must be maintained on an ongoing basis so that it will not reach the point where repair is impossible. In these cases preventive maintenance is vital.

V. TOTAL COMPLETION TIME

It is important to note that a military maintenance scheduling system can possess characteristics of open shop scheduling with a minimizing total completion time objective. [4] Consider the problem of minimizing total completion time. They consider a unit-time open shop with release time and a constant number of machines ($Om \mid p_{ij} = 1, r_i \geq 0 \mid \sum C_i$). *Om* represents an open shop in which there are *m* number of nonparallel machines, *pij* is the processing time of job *i* on machine *j*, *ri* is the release time of job *i*, and the objective is to minimize the total completion time. Note that a unit time open shop is one in which all processing times are equal to one. They present an *O*(*n2*) dynamic programming algorithm to solve this problem. They then apply this to problems in which each operation requires one unit of an additional resource. This allows many problems to be solved in polynomial time. They believe that there is always an optimal schedule for in cases where each job is completed before time *Ci+m2*. The authors state two conclusions. The first is that this algorithm is not useful for a problem in which there is a large number of machines. The second conclusion is that if the number of machines is part of the input, the problem remains open.

A discussion of the scheduling of a two-machine open shop system with a hierarchical objective of minimizing the total completion time that is subject to minimum makespan is presented in [5]. They illustrate by use of counterexamples the distinct structure of the $O2 \| \sum C_i \mid C_{\max}$ problem in comparison to the related $O2 \| \sum C_i$ problem. They showed that it is possible to develop polynomial-time heuristics for special cases of the problem as long as there is the presence of a strongly dominant machine or a strongly dominant job. They also illustrate how this case can be extended to a similar three-machine problem represented as follows: ($O3 \| \sum C_i \mid C_{\max}$).

The problem of scheduling in a system containing two-machine preemptive open shops is discussed in [6]. The author develops a dynamic programming algorithm that can optimally solve the problem in both weighted and un-weighted forms. He proposes an efficient heuristic for solving large-sized problems. His computational results show that this proposed algorithm can handle problems with up to 30 jobs within a reasonable amount of time. He states that this heuristic has an average percentage deviation of less than 0.5% from the optimal solution for problems with 30 jobs or less.

VI. Maintenance Scheduling Introduction

The previous section discussed how a scheduling environment that can be utilized by IMPRINT may be classified as open shop. However it should be understood that that application of IMPRINT is not restricted to any particular maintenance scheduling system category. In fact many maintenance systems are not open shop. Maintenance scheduling problems can be modeled as job shop scheduling problems [7]. This is accomplished by first allowing a job in the job shop problem to be the maintenance work order. In this same way a machine in the job shop problem is considered to be a maintenance worker. This method transforms the job shop problem into a problem of scheduling workers to process work orders. In this context, a work order is created for preventive maintenance or for repair of machine breakdown. In order to gain insight into the relationship between scheduling theory and the notion of maintenance scheduling, the thesis first describes assumptions that define the traditional scheduling problem and then highlights the characteristics of the maintenance scheduling problem that distinguish it from the conventional scheduling framework.

6.1 Conventional Scheduling

Classical scheduling theory is well known to be inadequate in dealing with many real world problems. [8] lists the twelve assumptions that are common in the development of the classical scheduling theory. These twelve assumptions are discussed in brief.

1. The classical scheduling theory classifies an entity as being any job that is denoted by a work order. This means that a work order can actually be processed by one or more workers depending on the need for skills and the size of the job. The problem with this assumption is that it requires workers to process each operation of the work order in series. In other words, according to this assumption, workers are not allowed to work simultaneously on the same order.
2. Classical scheduling theory prohibits preemption. However, the ability to pre-empt a schedule is vital in any maintenance environment due to production breakdowns and other unpredictable events. Preemption allows the ability for workers to be reassigned to a different work order based on prioritization of jobs. In the same context, preemption also allows work orders to be fulfilled in stages, instead of having to be performed all at one time.

3. Each job has a specified number of operations, with no more than one operation per machine. This limits the ability of a worker to process more than one individual operation for each work order. This assumption disallows job cancellations, which limits the problem to being only deterministic in nature.
4. Classical scheduling theory assumes that processing times are independent of schedule. This assumption does not hold true in situations where the set-up time for a maintenance job is dependent on which job precedes it.
5. In process inventory allowance is permitted.
6. Maintenance workers with similar skills can be modeled as parallel machines with nonidentical processing speeds.
7. Machines (and consequently workers as well) are allowed to be idle.
8. A machine may not process more than a single operation at any given time. However, [7] states that this assumption does allow for a maintenance worker to work on two or more work orders as long as the work orders are close by (i.e., at the same location).
9. Machines (or workers) never break down, and are available throughout the scheduling period.
10. Technological constraints are always known in advance.
11. There is no randomness (everything is deterministic). Both the number of jobs and machines are fixed. The processing and ready times are known and fixed as well.
12. There are no cancellations. This means that once a job for corrective maintenance is scheduled, it cannot be unscheduled.

6.2 Maintenance Scheduling

Has also identified characteristics of maintenance scheduling which distinguish it from other scheduling archetypes. These characteristics are as follows:

1. Non-repetitive jobs are inherent to maintenance scheduling problems (i.e., all jobs do not have to be the same; each job can be different from one another).Maintenance jobs all have varying difficulties,performed tasks,and completion times.
2. Maintenance jobs include a dynamic diagnostic process. The scope of a required maintenance on a machine cannot be fully known until every problem is identified. This means that the complete nature of a maintenance task is not known until some form of diagnostic is performed. In reality, the amount of required maintenance can either be greater than or less than what is first projected.
3. Preventive maintenance due dates are specified as preferred time intervals. However, these dates (or schedules) can be changed (optimized) once objective criteria are selected. These objective criteria can include an accommodation of maintenance worker traveling time, to schedule concurrently with a breakdown task on the same machine, or a preventive maintenance task may be scheduled early to occur simultaneously with the downtime policy of an organization.
4. Maintenance scheduling also has the ability to be altered due to outside factors such as the rescheduling of other tasks.
5. Maintenance tasks do not have a fixed scope. Scheduling maintenance for machine breakdown requires the scheduler to consider various contingencies.
6. Maintenance scheduling must decide whether to schedule the maximum amount of maintenance allowed in order to perform all possible preventive maintenance requirements.
7. Maintenance schedulers commonly schedule only the minimum amount of maintenance that is necessary in order to get the machine back online.
8. Maintenance scheduling schedules for a level of maintenance that is somewhere in between the maximum and the minimum possibilities based on economic justifications.

VII. CONCLUSION

A brief summary of the research areas within maintenance, modeling, and scheduling was given. The foundational aspects of maintenance modeling were presented also. The differences between conventional scheduling and maintenance scheduling have been shown. This research has determined that it is beneficial to view certain maintenance scheduling environments that are modeled by IMPRINT as open shop environments. The objective of this maintenance scheduling environment is to increase the amount of time that the military systems are available. The article has briefly covered some of the pertinent issues related to understanding IMPRINT. Because IMPRINT is a tool that can be used for maintenance modeling and analysis, understanding these scheduling issues are important for proper utilization of this tool. This paper has not discussed possible applications of IMPRINT outside of maintenance scheduling. Other uses for this tool may be available. More work could be performed in order to determine optimum uses for IMPRINT.

REFERENCES

[1] ARL (2000). "IMPRINT Analysis Guide."
[2] Duffuaa, S. O.. *Maintenance modeling and optimization*. (Boston, Kluwer Academic Publisher, 2000).
[3] Nahmias, S. *Production and Operations Analysis*, (McGraw-Hill/Irwin, 2001).
[4] Woeginger, T. A.. Minimizing the total completion time in a unit-time open shop with release times. *Operations Research Letters* (20), 1997, 207 - 212.
[5] Koulamas, K. A.. Open shop scheduling with makespan and total completion time criteria. Computer and Operations Research (27): 2000, 15 - 27.
[6] Liaw, C.-F.. Scheduling two-machine preemptive open shops to minimize total completion time. Computers and Operations Research, 2003.
[7] Leigh, W., & Paz, N. (1993). Maintenance scheduling: issues, results and research needs. *International Journal of Operations and Production Management*. 1993, 47 - 69.
[8] French, S. (1982). *Sequencing and scheduling: An Introduction to the Mathematics of the Job Shop*. (Chichester, Ellis Horwood Limited, 1982).