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Dispatching strategies for managing uncertainties in automated manufacturing systems

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ABSTRACT

Manufacturers in the western world need to exploit and perfect all their strengths to reduce the flight of manufacturing to global outsourcing destinations. Use of automated manufacturing systems (AMSs) is one such strength that needs to be improved to perfection. One area for improvement is the management of uncertainties on the production floor. This paper explores strategies for modifying detailed event list schedules following the occurrence of an interruption. Advanced planning and scheduling (APS) software packages provide a detailed advance plan of production events. However, the execution of this advance plan is disrupted by a myriad of unanticipated interruptions, such as machine breakdowns, yield variations, and hot jobs. The alternatives available to respond to such interruptions can be classified in four groups: regenerating the complete schedule using APS, switching to dispatching mode, modifying the existing schedule, and continuing to follow the schedule and letting the production system gradually absorb the impact of the interruption. Regeneration of the complete schedule using APS requires a large computation effort, may result in large changes in the schedule, and hence is not recommended. This paper reports on an experimental study for evaluating 10 strategies for responding to machine failures in AMSs that broadly fall in the latter three groups. The strategies are evaluated using simulation under an experimental design with manufacturing scenario, load level, severity and duration of interruptions as factors. The results are analyzed to understand the strengths and weaknesses of the considered strategies and develop recommendations.

1. Introduction

Recent years have seen a rapid loss of manufacturing in the western world to overseas destinations. Some of the labor intensive industries have completely disappeared from the western world. The western world still has a significant amount of high tech and capital intensive manufacturing such as semiconductor and automobile industries. The remaining manufacturing industry has a majority of those segments that rely on automation. Western manufacturers need to continually improve the technology and use of automated manufacturing systems (AMSs) to retain the associated industries. They need to pursue perfection in development and use of AMSs to raise the competitive barrier.

AMSs have developed over the years since the advent of flexible manufacturing system (FMSs) in 1980s. Though the 1980s vision of completely lights out factories has not become a reality, a number of technical challenges towards that goal have been addressed. At the same time a number of aspects offer further room for improvement and drive to perfection. One of the fronts that continues to offer opportunities for further improvement is the handling of uncertainties on the production floor. The uncertainties on production floor emanate from machine and equipment failures, yield variations, hot job arrivals, etc. The operation of an AMS is often administered based on a pre-generated plan, also referred to as an event list schedule, provided by an advanced planning and scheduling (APS) software. Automated control systems execute the sequence of events provided in the schedule. Occurrence of unplanned events makes it difficult and in some cases impossible to follow the pre-generated schedule. Strategies need to be defined for automatic response to unplanned events to reduce the uncertainties. The two major objectives in using such strategies are: quick modification of the schedule and minimum disruption to the completion dates and times of the current orders. The practical relevance of the problem is indicated by a proof of concept reactive scheduling system with similar objectives recently evaluated at the Siemens *Smart*Automation Lab (Lamparter, Legat, Lepratti, Scharnagl, & Jordan, 2011).

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The strategies for responding to interruptions can fall in any of the following four classes: no change to original schedule, modifying the pre-generated schedule, switching to dispatching mode, and regenerating the schedule. No change to original schedule involves continuing to follow the original planned schedule as far as possible. Rules are defined and used for the implementation of operations that are not on schedule. Modification of pre-generated schedule can range from simple to complex methods with the intent of trying to catch up with the original plan. Switching to dispatching mode has the downside potential of widespread changes in delivery times and dates to customers but it does offer ease of implementation and reactivity to production floor events. Dispatching heuristics may be designed to reduce the changes in promised delivery times and dates to customers to ameliorate the downside potential. Regenerating the schedule has become more attractive with increasing computation speeds and better access to production floor events; however, it has the down side of potential widespread changes in delivery times.

The operations manager is thus faced with a number of options for strategies to reduce uncertainties on the production floor of an automated manufacturing system. This paper provides guidance to operations manager by evaluating the strategies in the three classes that attempt to achieve the delivery dates of the pre-planned schedule as far as possible: no change to original schedule, modifying the pre-generated schedule, and switching to dispatching mode. Strategies using complete regeneration of the schedule are generally not recommended given the potential for widespread changes in delivery times and dates to customers and hence not considered in this study. The strategies make decisions ranging from none to multiple machine re-assignments, machining operations re-sequencing, and transportation operations re-assignments and re-sequencing.

The strategies are evaluated in three different AMSs using simulation. The three different real-life AMSs share the following characteristics: alternative machines for operations, limited buffers, load–unload operations, automated guided vehicles for transportation, and off-line operations. Two of the systems have re-entrant routing.

This section introduced the context of this study related to strategies dealing with uncertainties in AMSs. Section 2 provides a background of research in this area. Section 3 presents the 10 strategies considered in this study. Section 4 describes the methodology including the experimental factors used. Section 5 discusses the results of the experiment. A list of lessons learned applicable to practice is drawn in Section 6. It concludes the paper with discussion of future work.

2. Background

The reader is referred to Aytug, Lawley, McKay, Mohan, and Uzsoy (2005) for a rather comprehensive review of research on schedule execution in face of uncertainties and only a selected number of very relevant and more recent studies are discussed here using the grouping they proposed. Aytug et al. (2005) grouped the research into completely reactive, robust, and predictive-reactive scheduling approaches. In a more recent but less extensive review, Chaari, Chaabane, Aissani and Trentesaux (2014) replaced the third group with hybrid approaches and split that into sub-groups of predictive-reactive and proactive-reactive approaches. This paper utilizes the three basic groups by Aytug et al. (2005) and utilizes the hybrid approaches as an additional group for more flexibility.

The completely reactive approach dispatches jobs arriving into the system and at different machines using myopic priority rules or local optimization. The arrival of jobs into the system is determined at higher levels based on either forecasted demand or committed orders. These approaches are relatively easy to implement and have been often used in semiconductor industry in particular (Obeid, Dauzère-Pérès, & Yugma, 2014). Some of the recent efforts employing a completely reactive scheduling approach include Piplani and Wetjens (2007) and Georgiadis and Michaloudis (2012). A major disadvantage of the completely reactive approach is the highly volatile completion times of the jobs that make it hard to schedule supporting activities such a materials management and order promising.

Robust scheduling approaches aim to develop schedules that minimize the impact of interruptions when implemented. The schedules may be created after exploring a number of potential scenarios and aiming to achieve good performance in the worst possible scenario. It is reported that this achieves reasonable performance across all the scenarios (Aytug et al., 2005). Xiong, Xing and Chen (2013) present an evolutionary algorithm for robust scheduling of flexible job shops and demonstrate that it performs well when implemented with proposed robustness measures based on breakdown probability and location. Robust schedules may be perceived as generating longer makespans than other approaches and thus as less desirable.

The predictive-reactive scheduling approaches involve developing a pre-planned schedule (predictive) and using strategies to respond to interruptions that may occur during implementation (reactive). These approaches are the context for this paper as discussed in the previous section and hence a number of relevant efforts are discussed.

The practice in low-volume-high-variety and batch manufacturing environments largely utilizes pre-planned schedules based on the solutions available from commercial vendors. This area hence needs to be addressed by those interested in keeping the edge in AMSs which are typically used in such environments. In one of the early efforts, Bean, Birge, Mittenthal and Noon (1991) used the predictive-reactive framework and developed optimization approaches to modify the schedule for a short period following an interruption with the goal of matching up with the pre-planned schedule at the end of the period. Zakaria and Petrovic (2012) use match-up rescheduling using genetic algorithms for disruptions caused by new job arrivals and show that a strategy that manipulates idle times on machines performs better than total rescheduling for a 6 machine 13 job problem. Moratori, Petrovic and Vazquez-Rodriguez (2012) implement the same approach with data from industry for normal and urgent job arrivals and achieve good performance. The researchers propose to include machine breakdowns in their future efforts.

The response to unplanned events needs to be surgical in nature to avoid large scale changes in the schedule and in promised delivery times and dates. Sabuncuoglu and Bayiz (2000) compared switching to dispatching rules that generates many changes to schedule with beam search algorithm for partial scheduling in response to occurrence of interruptions. They found that dispatching rules performed well in face of stochastic disturbances and the partial scheduling approach could match their performance with more frequent scheduling. The algorithmic approach performed better for non-uniform machine load scenarios.

Hou and Li (2012) identify the conditions under which a repair to schedule may be feasible versus the need for complete rescheduling. Li and Murata (2012) demonstrate that a method comprised of binary particle swarm optimization and simulated annealing performs well for rescheduling of large size problems, defined as those taking more than 2 hours of computation time. The largest problem included had 16 machines, 4 each of 4 types. The method may have too long computation time for industrial application.

Liu and Zhou (2013) present polynomial time algorithms to reschedule identical parallel machines following disruptions caused by rework jobs with the objectives of minimizing number of jobs assigned to different machines compared to the original schedule and the total completion time. The provided results are limited to a 4 machine problem. Gürel and Cincioğlu (2015) developed a heuristics based on objectives of minimizing the number of jobs delayed beyond their original completion times and the manufacturing cost.