A Holonic Approach to Reactive Scheduling when Rush Orders Emerge

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Abstract
Rush orders can complicate the life of project managers when they emerge especially if they are of a high priority. Initially prepared process plans and schedules become invalid while extra capacity may be needed to meet the new demands placed on the shop-floor. However, with the era of distributed manufacturing, skills and resources can be shared in an optimal manner. The paper presents an application for automated management of resources in response to varying demands experienced by an industrial cluster of tool and dies workshops. A set of holons are utilized to monitor progress of orders in process while responding in real time to new demands placed on the system. The system utilizes the Petri-net protocol for the bidding function and automatically organizes the manufacturing function in a cost effective and timely manner. The ARENA discrete event simulation platform was utilized to demonstrate system's results in a virtual environment.

Keywords
Rush Order, Predictive schedule, Reactive schedule, Petri-net protocol, Holon, Holarchy

1 INTRODUCTION

Customers in the 21st century are increasingly becoming complex. Nowadays, it is the norm for businesses to experience ever changing requirements and needs from their unpredictable clients. Among these changes, a sudden increase in production demand due to rush orders is a main problem most manufacturers face. New orders can be introduced at any time with urgent due dates resulting in work-in-progress increase thus disrupting work flow within the production system.

Dewa et al. [1] identified rush orders as one job-related operational disturbance Tool, Die and Mould-making (TDM) firms in the South African Western Cape Province have suffered. When rush orders emerge, the previously prepared predictive schedule is rendered invalid and a new reactive schedule is required to maintain system performance.

In the paper, we suggest a holonic framework for reactive scheduling for scenarios where rush orders emerge. A case study based on a tool and die workshop in the Western Cape Province of South Africa is employed to demonstrate the approach. The structure of the paper is as follows: firstly, the impact of rush orders on the production shop-floor is discussed. Secondly we define the problem context using a case study before proposing a holonic model blue print for reactive scheduling. Finally we present the simulation study results of the proposed system.

2 LITERATURE REVIEW

2.1 The operational impact of rush orders

According to Wu and Chen [2], rush orders are immediate customer jobs that exceed the expectation of a currently operational Master Production Schedule (MPS). They may result from the arrival of new urgent orders, increase of volumes of pending orders or change of due dates of pending jobs to an earlier date. In a majority of production firms, the sales teams usually accept rush orders since they increase firm revenue and future clients. On the other hand, the production shop-floor rejects rush-orders due the strain they inflict on production planning, scheduling decisions and available resource capacity.

Integrating a rush order into an existing prepared predictive schedule can be challenging due to the impact they inflict on any production line. Researchers have identified numerous problems caused by rush orders.

2.1.1 Delay of Standarad Orders

Studies by Plossl [3] have revealed that there is a clear correlation between the acceptance of rush orders and the delay of scheduled standard orders. An increase in the number of rush orders accepted exponentially increases the time it takes to complete pending standard orders. Since rush orders are always prioritized, the throughput time of standard orders is extended as illustrated in Figure 1, a model developed by Trzyna et al. [4] to demonstrate the extent to which rush orders are delayed by standard orders.

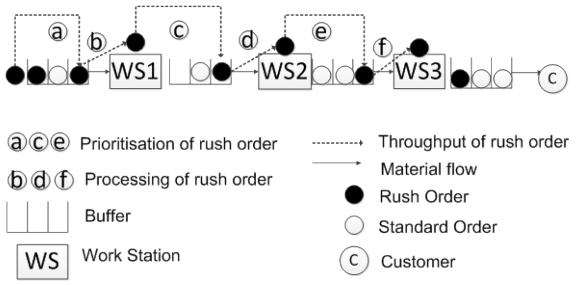

Figure 1 - Behaviour of rush orders (Trzyna et al., [4])

Wiendahl [5] added that the throughput time for any order results from the sum of order processing and interoperation times. The interoperation times for standard orders are significantly increased by the presence of rush orders.

2.1.2 Increase in inventory costs

Rush orders also impact significantly on Work-In-Process (WIP) levels. The more the rush orders the longer the lead times for standard orders and hence the higher the inventory holding costs.

2.1.3 Complexity in production planning and scheduling

The prepared shop-floor schedule with standard orders is rendered invalid when rush orders are added. Due to this challenge, rush orders need to be integrated into an existing plan in an optimal manner. A lot of research has been conducted on the decision of incorporating rush orders into an existing schedule. Studies by Wu and Chen [2] evaluated whether rush order revenue was worth it or not by taking into account the expenditure of tardiness costs invoked onto the standard orders. However, other researchers have considered the lateness factor only in making the decision.

2.2 Challenge of rush orders in tool-making firms

The South African TDM industry has been coined as a critical sector to the growth and sustainability of manufacturers in the nation. However, results of a recent benchmarking survey of the TDM sector (Malherbe, [6]) have revealed that most firms are struggling in the area of delivery lead times as compared to their global competitors [7]. Though the reasons for this trend are manifold, Mkhize [8] highlighted that in most of these firms, workflow is interrupted by the frequent occurrence of rush orders [8]. This trend has resulted in a significant compromise on delivery due dates.

However, due to intense global competition among tool-makers, the strategy of collaborative manufacturing is slowly gaining popularity in the Tool, Die and Mould-making sector. South African toolmakers have realized the need to focus on their core competencies and narrow their scope of value addition during the fulfilment of orders. As a result collaborative networks which share skills and resources are being formulated with the goal of expanding the resource capacity base. Eventually the firms position themselves to accept large orders. This makes the current manufacturing environment a distributed one.

2.2.1 Problem statement

Much research in the past has focused on how to deal with rush orders within a production shop-floor where the decision of accepting or rejecting a rush order is based only of the available capacity in a single workshop. Examples of such scholarly efforts include work by Chen [9] who formulated a heuristic model for justifying acceptance of rush orders. However, with the era of distributed manufacturing, the question remaining is: how best can rush orders be planned for in a distributed manufacturing environment? This paper attempts to answer the question through a framework designed using the South African tooling industry as a case study.

2.2.2 Holonic Control System for South African Tool Die and Mould-makers

Due to the unique reality of collaborative manufacturing and challenge of rush orders mentioned in the problem statement, novel applications or models are required by South African Tool makers. Holonic Control systems are a possible solution for handling shop-floor disturbances for firms operating in a distributed manufacturing environment [10].

Holons are a special type of autonomous agents which have the ability to make decisions and execute tasks on behalf of users. They are autonomous and cooperative building blocks of a manufacturing system capable of transforming, transporting and/or validating information or physical objects [11]. Holons are a special class of agents as illustrated in the work by Girret and Botti [12]. Their design and deployment assist in solving problems for cases where frequent disturbances are affecting operations. A holonic approach was used because the resulting architecture will be highly resilient to external and internal disturbances while it is adaptable to changes. When different holons interact to solve a problem, they formulate a holarchy.

Holons have been used to solve other production planning problems in manufacturing. Babiceanu et al. [13] used a holonic approach to solve material handling operations in a dynamic manufacturing environment. Akturk and Turkcan [14] applied a holonic approach to part-family and machine-cell family problems in a cellular manufacturing environment. The holarchy classes presented in the paper were specifically designed to handle rush orders during distributed production.

3 RESEARCH METHODOLOGY

Since Holons are a specific class of agents, frameworks for developing agents can be used to realise them. Hence, the Designing Agent-based

Control Systems (DACS) methodology proposed by Bussmann et al. [15] was selected as the appropriate methodology of building the system blue print. The steps taken in this methodology are illustrated in Figure 2.

Specification of the production system problem context is the main input of this methodology. A case study of five tool rooms forming a collaborative cluster in the Western Cape Province of South Africa was utilized. The data concerning these firms was derived from field visits and facility tours.

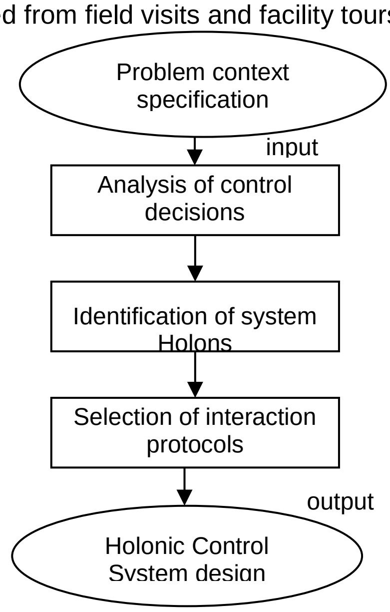

Figure 2 - Steps in DACS methodology [13]

The five firms were randomly selected based on their collaboration in producing parts for the automotive industry. The purpose of the field studies was to observe the system resources within the firms and investigate the frequency of occurrence of rush orders during weekly production. All firms agreed to take part in the study and as such they were visited during different time periods. The expert opinion method was used to select the appropriate respondents who in this case were shop-floor operations managers in their firms. The variables in the observation schedule questionnaire were:

- Main products and process flow methods
- The frequency of rush orders in the firms
- Predictive scheduling heuristic rule employed
- Reactive scheduling heuristic rule employed

The purpose of this analysis was for understanding of the problem context. A facility tour was also conducted in each of the firms. For the purposes of this study, only a single main product was selected. Secondly, a simulation study was conducted for one of the observed firms. A simple job-shop manufacturing firm which produces sintered car sensor rings was selected for this purpose. The purpose of the simulation study was for evaluation of different decision strategies the developed holarchy suggests in response to rush orders so as to minimize delays in standard orders. Discrete event simulation is an essential tool for testing different scheduling strategies without affecting the real-world system [16]. Arena 14.0 discrete event simulation package (research version) was employed for this purpose. The information derived to define the problem context was employed for analysis of the control decisions, identification of the required holons and selection of the appropriate interaction protocols.

3.1 Case study: Problem context

The selected case study is a tool room using semi-automated production flow-line. The firm produces powder metallurgy parts for cars such as sensor rings, flanges, lock components and pump components. The case study will focus on different orders (both standard and rush) of the main product identified which is the sensor ring. When a rush order is introduced to the system, it is added to the beginning of the queue. The process flow diagram for the sensor ring fabrication process is shown in Figure 3 while the order data used in the simulation study is shown in Table 1.

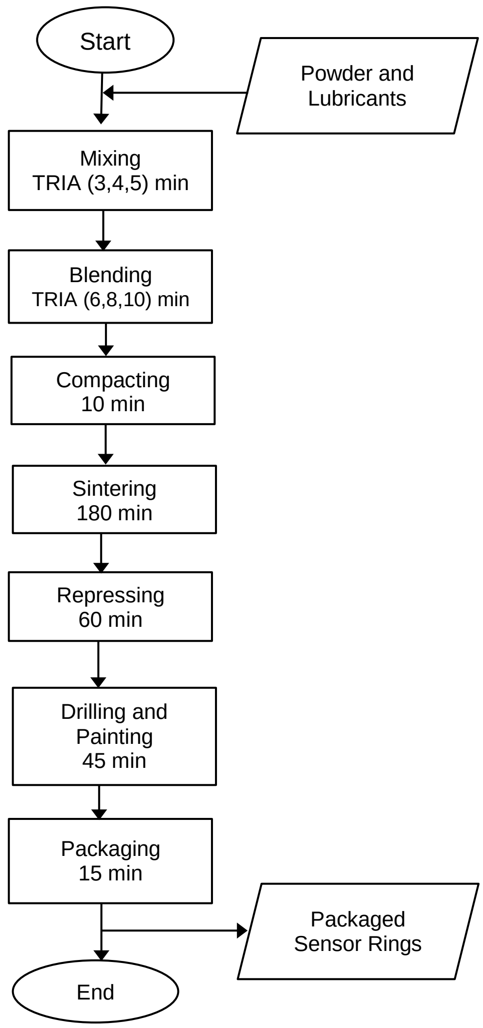

Figure 3 - Process flow diagram

3.2 Facility Layout Diagram

The manufacturing facility for the tool work shop under study is a small facility with 10 operators and 11 system resources. The facility layout is illustrated in Figure 4 while the system components for the facility are given in Table 2. A mapping of processes and components required at each stage are clearly given in Table 3.

According to the manufacturing facility's perspective (derived from the field studies), the total throughput time of standard orders is too high whenever there are rush orders introduced. This delay renders the facility uncompetitive when it comes to delivery due dates. Hence, lead time reduction for both standard and rush orders is crucial to enhance the productivity and the competitiveness of the plant.

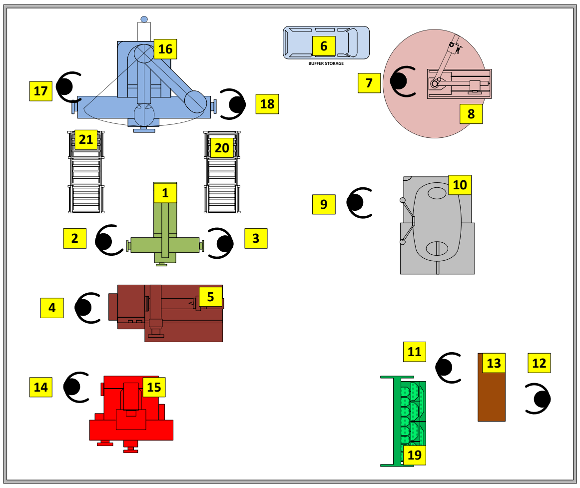

Figure 4 - Manufacturing facility diagram

The resources shown in the facility are arranged following a job-shop set up which is being used to fabricate different parts. However, the orders presented in Table 1 are the ones utilized to illustrate the functioning of the designed framework.

4 RESULTS OBTAINED

4.1 Holonic framework developed

Using the production problem described in Section 3.1, the Holonic model blue print for dealing with rush orders was developed using the Java Agent Development Framework (JADE). The main objective of the system is to minimize tardiness costs associated with the lateness of standard orders due to rush orders by searching and allocating more resources from within a cluster's available capacity.

4.1.1 Analysis of control decisions

To minimize the effect imposed by rush orders, the key decisions the system should be capable of making are:

- Order definition (standard or rush)
- Process flow mapping
- Resource searching
- Resource availability assesment
- Resource allocation

The control parameters for the decisions include throughput time and tardiness costs.

4.1.2 Holon definition

The identified control decisions were utilized to define the required holons for the system. The identified holons include:

- ✓ Order Holon (OH)
- ✓ Resource Holon (RH)
- ✓ Supervisor Holon (SH)

Every incoming order results in the creation of an Order Holon (OH). The Order Holon carries order data concerning due dates and process flows. Order Holons have to compete for Resource Holons (RHs). The Resource Holons carry information concerning the available operational resources required to do tasks. Information on capability and availability are made available in the RHs. The Supervisor Holon has a bird's eye view of the entire system is responsible for close monitoring of the progress of all Order Holons. The hierachial structure of the holons is represented in Figure 5.

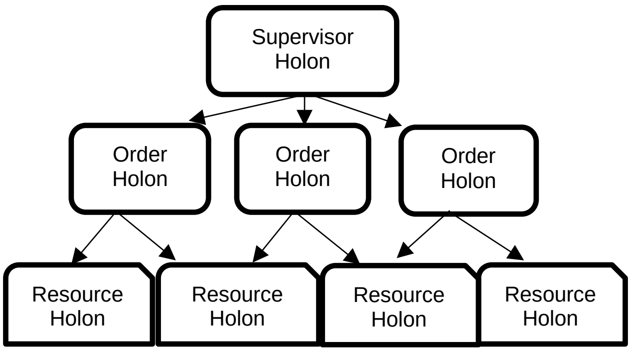

Figure 5 - Holarchy diagram

4.1.3 Interaction protocols

Order Holons have to compete and bid for resources during the searching process. The appropriate protocol selected to achieve this goal in the holarchy was the Petri-Net Protocol. The Resources advertise their availability and costs within a virtual environment and the Supervisor Holon makes the final decision on which resources are selected for the job based on minimizing the tardiness costs.

4.2 Simulation study

4.2.1 Model Logic

The simulation model for the tool room under study was fully developed using the ARENA 14.0 research version. The shop-floor manager approved the model behaviour during the verification process and using historical input data of previous orders, the model was validated. For demonstrating the decision making of the holarchy described in Section 4.1.3, resource data on the tool rooms visited were stored on an Excel spread sheet which was linked to the simulation model and a Java Agent Development Platform with the holons.

Upon entry of a rush order, the Order Holons bid for Resource Holons available. The Supervisor Holon finally reallocates and develops a reactive schedule with the minimum tardiness costs and low impact on throughput of standard orders.

4.2.2 Model Results

The results for the simulation study are summarized in Table 4. The Job lateness was significantly reduced when using the Holonic Approach resulting in a 65% tardiness cost reduction.

5 CONCLUSION

5.1 Discussion

Organizations within collaborative networks can take advantage of the resources and skills available to them within a network to facilitate handling of orders. To facilitate resource allocation during manufacturing in a distributed environment, holons can be designed and developed for global decision making. The flow diagram in Figure 6 illustrates the proposed approach to reactive scheduling using the paradigm of holons.

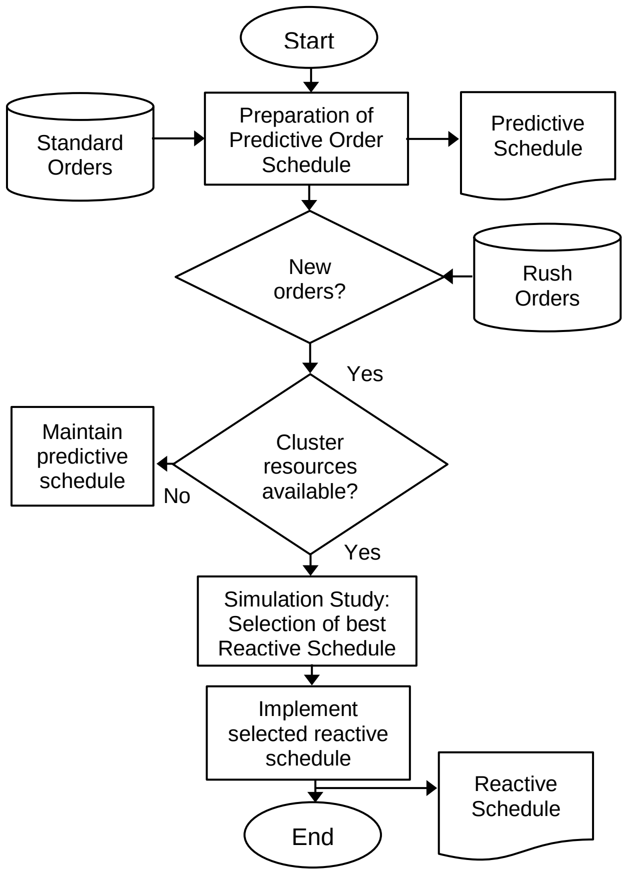

Figure 6 - Proposed reactive scheduling approach

The designed framework serves as a decision support system for real-time scheduling when interruptions due to rush orders emerge. The required capacity can be found and allocated in response to the sudden demand increase hence significantly minimizing waiting time.

5.2 Future work

The study was on design of a holonic blue-print for reactive scheduling when rush orders emerge with the goal of minimizing tardiness costs. Future work can be done on developing other holonic systems to handle other disturbances like machine breakdowns in a real-world firm environment.

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8 BIOGRAPHY

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Order Number	Volume required	Order Type	Due Date
001	5	Standard	14 days
002	7	Rush	3 days
003	6	Rush	5 days
004	3	Standard	20 days
005	9	Rush	7 days

Table 1 - Standard and Rush Order Data

Number	Name of Resource
1	Mixing and compacting machine
2	Operator 1
3	Operator 2
4	Operator 3
5	Milling centre
6	Buffer storage space
7	Operator 4
8	CNC Machine
9	Operator 5
10	Drill press
11	Operator 6
12	Operator 7
13	Workbench
14	Operator 8
15	Lathe machine
16	Blending Machine
17	Operator 9
18	Operator 10
19	Delivery rack
20	Push rack 1
21	Push rack 2

Table 2 - Manufacturing facility system components

Process	Components
Mixing	Mixing and compacting machine, Operator 1 and Operator 2
Blending	Blending machine, Operator 9 and Operator 10
Compacting	Operator 3 and Mill Press
Sintering	Operator 4 and CNC machine
Repressing	Lathe Machine and Operator 8
Drilling	Drill Press and Operator 5
Painting	Operator 6, Operator 7 and Workbench
Packaging	Operator 6, Operator 7 and Workbench

Table 3 - Process-system data relationship

Order Number	Order Type	Completion Date		Lateness/Tardiness		Tardiness Cost (R20/day)	
		Normal	**Holonic**	**Normal**	**Holonic**	**Normal (Rands)**	**Holonic (Rands)**
001	Standard	15 days	14.2 days	1 day	0.8 days	20	16
002	Rush	16 days	7 days	13 days	4 days	260	80
003	Rush	18 days	9 days	13 days	4 days	260	80
004	Standard	24 days	15 days	4 days	0 days	80	0
005	Rush	32 days	18 days	25 days	11 days	500	220
Total Tardiness Costs						**1120**	**396**

Table 4 - Summary of Simulation study results