An Optimization of Manufacturing Systems using a Feedback Control Scheduling Model

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Abstract. In complex production system that involves multiple process, unplanned disruption often turn to make the entire production system vulnerable to a number of problems which leads to customer’s dissatisfaction. However, this problem has been an ongoing problem that requires a research and methods to streamline the entire process or develop a model that will address it, in contrast to this, we have developed a feedback scheduling model that can minimize some of this problem and after a number of experiment, it shows that some of this problems can be eliminated if the correct remedial actions are implemented on time.

1. Introduction

Now our days, manufacturing companies generate and update production scheduling which is a very critical part in the production process in converting raw materials into useful output. Scheduling allocates the start and finishing time to each particular order of jobs and by also bringing productive operations in the shop floor which actually provide a calendar of step after step for processing a set of jobs using machine, and all other required resources. In the real world situation where we have very complex manufacturing systems, operation managers, line managers and supervisors must not only generate high-quality schedules but also react quickly to unforeseen disturbance that upset the entire production process, in the most economical way that will benefit the company and the customers. This unexpected disturbance are generally difficult to anticipate during the production process, so there is a need to develop a strategic feedback re-scheduling model that can streamline and accommodate this unforeseen disturbance in order to prevent the system to degenerate to a complete short down or defects to products, causing a complete disaster to the economic well-being of the company.

Actually in real practice, production scheduling is a complex system within the manufacturing process that has the flow of information, processes and decision-making that forms part of the manufacturing planning and control system.

In recent years, more attention has been given to the uncertainties while designing schedule models but in the manufacturing shop floor, is practically impossible to know a period or the time when the system can be subjected to a disruption.

1.1. Scheduling

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According to Katrina et al, [1] this scheduling problem has commonly be defined in academic literature with emphasizes only on a limited part of the scheduling task. From the aforementioned, following the exact scheduling in a real manufacturing facility as it was designed, is practically impossible due to the difficulties in having an accurate estimation of time estimation for data processing and also the unforeseen disruptions that affects the system.

In justification of the aforementioned, a recent research carried out by Pinedo [2] enumerates a number of difference between theoretical models and real-life production scheduling problems which includes:

- The constant arrivals of new jobs into the system,
- Complicated machine environment etc.
- Processing time not following the statistical distribution,
- Discounts, and activities to become

He remarks that the emphasis of rescheduling problem is not sufficient in the literature of production scheduling models and concluded that when designing a scheduling system, uncertainties need to be taken into account, since as production schedules becomes inaccurate or infeasible as time goes on, requiring a new schedule.

With respect to rescheduling model and approached found in research work, deals with mathematical models in order to optimize the production system, Dutta et al [3], Davenport, [4]. However, these approaches and their results remain well-grounded because the can only be applicable to specific problems and cannot be applicable with complex problems. According to Aytuy and Mchay [5] simulation has been employed in a number of papers in order to validate proposed method of rescheduling and algorithms but this methods also remain grounded because the results needs to be interpreted according to the simulation system being used.

In view of this limitations, our main objective in this paper is to come up with a supply chain rescheduling model as a feedback control system that can minimize the effects of this disturbances in the real manufacturing environments were the system is complex due to a number of unforeseen situations. In a similar research work, Vieira et al. [6] also presented a rescheduling framework that can be used for classifying and describing rescheduling environments, policies, strategies, and methods. According to his findings, production scheduling theory has had limited impact on real life practice because most scheduling results do not consider important characteristics of the environment in which scheduling occurs. From the aforementioned, it is evidence that researchers have not considered the full dynamical aspects of the manufacturing system, including the planning and control systems.

The relationship between the theory and practice of scheduling was also later discussed by McKay and Wiers [7] here, they describe three principles that explain a practical production scheduling system which includes, (generates partial solutions for partial problems, anticipating and reactions for disruptions, and also being very sensitive in adjusting the time in production situation).

In this paper, we proposed a conceptualized feedback rescheduling model which will be able to control and take care or minimize the effect of these disturbances that makes the production system and activities to become vulnerable.

2. Production Systems

Production/operations management is a process, which combines various activities, systems and resource to transform raw materials into useful good or service. This activities take place in a controlled method and environment. These set of interrelated management activities which involves input require product/service having the requisite quality level, and the set of interrelated management activities, which are involved in product manufacturing called production management, while using the same concept in the service management, is called operation management Vollmann et.al [8].

All these set of activities and operation, need to be done in an orderly manner in order to achieve the key objectives of any manufacturing or service industry which is productivity out-put in order for the company to make money, attract more customs and expand globally.

2.1 Customers service
The main objective or initial principle of a system's operation is resource utilization which will satisfy the customer’s wants and also enable the organization to maximize its output. From the aforesaid, it shows that the customer service is a vital and strategic importance of operations management. The organization including all the various operating systems and methods has an obligation to provide product that exceeds the customer’s specification and satisfaction both in terms of cost, quality and timing. Thus, making sure that the ‘right product and process are being done at the right time, sequence and price’ can help to gratify the customer’s primary objective.

A number of these aspects are described in four functions in Table 1 which includes the primary sources of customer satisfaction and must actually reflect as the main objective for operations managers during their production process. According to Aytug, H., M. and G. F. Verisel [9], an organization will generally aim reliably and consistently to achieve a specific standard which the operation managers and shop-floor teams have put together, but due to the complex nature of manufacturing process and other influential situations, attempting to achieve these standards becomes almost practically impossible.

This further cursues a confusion that influences the operations manager’s decisions to a different plan of action to aid in achieving the required customer service, but due to unforeseen disturbance in real operation on the shop-flow, obtaining this new objectives or action plans sometimes become practically impossible and the need to be a backup system or methods in place to assist should in case the need arise.

| Table 1. Customer’s specifications and objectives sections. |
|-----------------------------------------------------------|
| The customer service objective | The resource utilizations objective |
| i.e. toward deliver contracted/acceptable levels of customer | i.e. to attain adequate levels of resource utilizations (or productivity) e.g. |
| i.e. to attain adequate levels of resource service (and hence customer satisfaction) through the supply of goods and services that meets the right specification, right cost and the right time. | achieving an agreed levels of utilizations of materials, machines and labour |

2.2 Resource Utilization
The Resources are very vital part of any organization because products are produced through them in order to satisfy customer. In addition to this, customer service must be provided with the achievement of effective operations through efficient use of resources. Inefficient use of resources or inadequate customer service leads to commercial failure of an operating system. Operations management is concerned essentially with the utilization of resources, i.e. obtaining maximum effect from resources or minimizing their loss, underutilization or waste. The extent of the utilization of the resources’ potential might be expressed in terms of the proportion of available time used or occupied, space utilization, levels of activity, etc. Each measure indicates the extent to which the potential or capacity of such resources is utilized. This is referred as the objective of resource utilization.

2.3 Operation managers
Operation management is concerned with the achievement of both satisfactory customer service and resource utilization. An improvement in one will often give rise to deterioration in the other. Often both cannot be maximized, and hence a satisfactory performance must be achieved on both objectives.
All the activities of operations management must be tackled with these two objectives in mind. This process are illustrated in figure 1. All this activities have to follow each other and should in case anyone is lacking within this scheduled process, then the entire system may become vulnerable to varieties of disturbance which is then transferred to the customer in the forms of: (late delivery, low quality product, and higher cost).

According to Ikome et. al. [10], Manufacturing facilities are complex, dynamic and stochastic in nature. Manufacturing systems usually have a wide variety of products and processes and this makes manufacturing managers to count or relay purely on the production schedules because it has a better coordination to increase productivity and minimize operational costs. It can identify resource conflicts, control the release of jobs to the shop, and ensure that required raw materials are ordered in time. In addition, it can also determine whether delivery promises can be met using a number of methods e.g processing methods.

3. Methodology
According to manufacturing and engineering principles, it is evidence that the production process is supposed to flow in an orderly sequence as shown in figure 1, because there are a number of activities and systems that need to perform a number of functions before the optimal goal could be achieved.

In this work, we have developed a feedback rescheduling model that is shown in figure2, which tries to minimize the effect of disruption. A case study company is used to test the model, by combining it with a number of equations to see the various relations. Due to confidentiality, the name of the company will not be mentioned.

Scheduling is the allocation of starts and finish time to each particular order. Therefore productivity improvement in a shop floor can be achieved through a proper scheduling which providing a calendar for processing a set of jobs. We are using a single machine to test the scheduling model, which consists of \( n \) jobs with the same single operation on each of the jobs, while the flow shop-scheduling consists of \( n \) jobs with \( m \) operations on each of the jobs. In this test, all the jobs will have the same process sequences. The job shop scheduling contains \( n \) jobs with \( m \) operations on each of the jobs; but, in this case, the process sequences of the jobs will be different from each other.

3.1 Model Concept using a single machine
The basic single machine scheduling problem is characterized by the following conditions:
A number or set of independent jobs are available for a single-operation with a processing time of zero.
Set-up time of each job is independent of its position in jobs sequence. So, the set-up time of each job can be included in its processing time and the Job descriptors are known in advance.
One machine is continuously available and is never kept idle when there is a disruption within the production line or when work is waiting.
Each job is processed till its completion without break.
Under these conditions, the correspondence of one-to-one between a sequence of the \( n \) jobs and a variation of the job indices 1, 2, ..., \( n \) is very visible and straightforward. The total number of sequences in the basic single machine is \( n! \) which is the number of different variation of \( n \) elements.

### 3.2 Characteristics of identifying problems during scheduling

The following five data are necessary in order to describe or determine any problem during the scheduling process of the model:

- **Processing time (\( t_j \))**: It is the time required to process job \( j \). The processing time, \( t_j \) does include both actual processing time and set-up time.
- **Ready time (\( r_j \))**: It is the time at which job \( j \) is available for processing. The ready time of the job is the difference between the arrival time of that job and the time at which that job is taken for processing. In this model, we condition \( r_j = 0 \) for all jobs.
- **Due date (\( d_j \))**: It is the time at which the job \( j \) is to be completed.
- **Completion time (\( C_j \))**: It is the time at which the job \( j \) is completed in a sequence. Performance measures for evaluating this scheduling model is a function of job completion time, and includes, (Flow time, Lateness, Tardiness, etc).
- **Flow time (\( F_j \))**: It is the amount of time job \( j \) spends in the system, and it indicates the waiting time of jobs in the system, this will give us some idea about the time it take to process the jobs on the system or work-in-progress (WIP).

- **Lateness (\( L_j \))**: It is the amount of time by which the completion time of job \( j \) differs from the due date (\( L_j = C_j - d \)). This will be use as a measure or idea about conformity of the jobs in the schedule model, to a given period of time or set of due dates of the jobs. This will either be positive lateness or negative lateness. Meaning the job is completed after its due date or before its due date. The positive lateness means poor service while negative lateness means better service. Note that, in many situations, distinct penalties and other costs are associated with positive lateness. So we are trying to minimize this using our model in order to prevent the company from facing this consequences.

The following equation had been derive and the different measures of performance which are used in the scheduling model are listed below:

\[
T_j = \max \{ O, C_j - d_j \} = \max \{ O, L_j \}.
\] (1)

Mean flow time: \( F = 1/n \)

Mean flow time: \( \bar{F} = 1/n \sum_{j=1}^{n} (F_j) \) (2)

Mean tardiness: \( \bar{T} = 1/n \sum_{j=1}^{n} (T_j) \) (3)

Maximum flow time: \( F_{\text{max}} = \max_{1 \leq j \leq n} F_j \) (4)

Maximum tardiness: \( T_{\text{max}} = \max_{1 \leq j \leq n} T_j \) (5)

Number of tardy jobs:
\[
N_T = \sum_{j=1}^{n} f(T_j) = \sum_{j=1}^{n} f(T_j)
\] (6)

Where: \( f(T_j) = 1, \) if \( T_j > 0 \), and \( f(T_j) = 0 \)

According to Ikome et. al. [11] in the manufacturing facilities, production scheduling are very vital part of the organization as it is a dynamic network or system that share information about
the manufacturing process in order to make decisions about which jobs should be done first. These information includes, job status, work orders, manufacturing resources, raw materials, work-in-process, people and production lines etc.

![Production Scheduling Model as a feedback Control System](image)

**Figure 2.** Production Scheduling Model as a feedback Control System.

4. Case Study and Testing Model
In this model, there are a number of jobs that have to be process. During the production process, there is a continuous update that informs the system about the Schedule status and the total number of jobs on the system. By so doing, it prevent raw material from flowing to the downstream should in case there is a disruption with the work-in-progress. This method minimizes defect and waste by not allowing more material to flow to the shop floor until the disruption is addressed. In an attempt to further strengthen this model, a backup generator is included on the system to eliminate the possibility of disruption due to power failure. In addition, there is also an emphasis for the employees to be cross train, this will help prevent the issue of zero productivity due to employee’s absenteeism.

The following are among the key decision areas in the feedback scheduling and control model that are taken into consideration:

- Releasing jobs for production,
- Power failure
- Determining when jobs should be started, and
- Assigning resources (people, equipment, or production lines) to jobs,
- Disrupted jobs that should be halted.
- Reassigning resources from one job to another,
- Employee absenteeism
- Unskilled employees.
- Prioritizing jobs that require the same resources,

Note that, after the schedule is generated, manufacturing operations begin and our objective is to see the shop floor following the schedule and also reacting during the unforeseen disturbance. In real practice the operators in the shop floor may deviate partially from the schedule. Preferably, the schedule should be followed as closely as possible. A number of Minor deviations which includes, (Minimum start and end times) are inevitable and are ignored.

According to Vieira et al. [12], Rescheduling is a key principle for understanding production scheduling systems. *Rescheduling* is the process of updating an existing production schedule in response to disruptions or other changes which includes different types of disturbances that can upset a production schedule, namely machine failures, processing time delays, rush orders, quality problems, and unavailable material. In our experiment, the rescheduling is done periodically in order to plan
activities for the next time period based on the state of the system and also occasionally in response to the magnitude of the disruptions. However, although this model looks simple, note that production scheduling systems are complex in nature because the mechanisms for sensing the state of the manufacturing system and generating updated production schedules cannot be expressed in detailed (except in very special cases) as mathematical functions. In addition, the randomness of disruptions and other uncertainties makes it difficult. The most realistic representation will be to view the systems as a decision-makers.

4.1 Model evaluation
In order to evaluate the model, an automotive gasket manufacturing company was taken as an applicable example for experiment. In the production line, considering it series set-up, there are five different work stations that perform a number of activities, each of this work station comprises of several machines, which execute functionally different processes.

5. Results
We considered a single machine production line that runs in series to do our experiment, sequencing the jobs in increasing order of processing time which is known as the shortest processing time (SPT) sequencing. We were mostly interested in minimizing the time spent by jobs in the system in order to minimize the work-in-process inventory. We also, had to pay some interested in the rapid turnaround/throughput times of the jobs.
One of our main objective was to find the optimal sequence, which will minimize the mean flow time and also obtain the minimum mean flow time after the system is disrupted due to unforeseen circumstances. The total number of jobs under this situation is five. We had to arrange the jobs in an orderly manner of Shortest Processing Time (SPT) please see table1, and fig 3. for results

| Job (j) | Processing time/Output (t) (hrs) |
|---------|---------------------------------|
| 1       | 15                              |
| 2       | 4                               |
| 3       | 5                               |
| 4       | 14                              |
| 5       | 8                               |

Table 2. No of Jobs to be process after Disruption.

![DISRUPTED JOBS](Image)

Figure 3. Disrupted flow.
In order to evaluate the model, a first test was done and the results are presented in table 2 and fig 4. From the results, it show the period when the was a disruption and there is a clear indication that the processing time does increase due to the disruption, requiring the workers to work overtime in order to meet up with the initial out-put set by management, and this is a situation that NO company want to find itself in. Please see the table 3 and the figure 4 that follows for further result after testing the model.

| Job (j) | Processing time/Out-put (t) (hrs) |
|---------|----------------------------------|
| 1       | 4                                |
| 2       | 5                                |
| 3       | 8                                |
| 4       | 14                               |
| 5       | 15                               |

By applying equation (2) to minimize the flow time after disruption of the jobs on the system, it show that the jobs sequence, which will minimize the mean flow time, is 2-3-5-4-1 and by computation of Fmin. Figure 3 further show the various processing time and expected out-put. Please see table 3 for results.

In order to further evaluate the feedback scheduling model, the approach of using a dual production line was taken in to consideration. In this duel production line, in total there are five different work piece variants from the raw material to the final product. Table 4, shows how this materials run through multi-level process chain which includes; Power press, bench grinding, and fly press, drilling and dies fixtures.
Table 4. Completion time and Total output percentage of jobs

| Job(j)      | Power Press | Bench Grinder | Fly Press | Drilling | Dies & Fixtures |
|-------------|-------------|---------------|-----------|----------|-----------------|
| Processing time (t) (hr) | 4           | 5             | 8         | 14       | 15              |
| Completion time (Cj) (Fj)  | 4           | 9             | 17        | 31       | 46              |
| Percentage      | 45%         | 53%           | 25%       | 68%      | 18%             |

Fig. 5 shows the final validation of the model, which indicated a high planning quality due to the minimization of disruption effect during the experiment. The real output of the production lines shows that after disruption, compared to previous scenarios, it improves the company’s average processing time by 19 percent.

6. Conclusion
In this work, a novel approach is presented, which show a number of gap between theoretical and real-life situation in manufacturing industries when disruption emerges, and also how manufacturing systems are very complex in nature. It further compares a number of methods that have been used in order to solve this problem and was unsuccessful because of the complex nature of the system, some were solved and others left out. Our model was developed using some of these unsolved problems and was tested in an automotive gasket manufacturing company, and the result shows that disruption can be minimize if the right steps are taken on time.

The depicted scenario focuses on the scheduling of single and dual production lines in a complex production system with an unlimited number of production orders and machines. In addition, we also anticipated that this research work will help Manufacturing managers and engineers, to improve their production scheduling system.

Future research will focus on a by-pass scheduling system that can automatically rectify any disruption.

7. Acknowledgments
The author will like appreciate the SA Automotive gasket manufacturing industry for granting us permission to their facility in order for the experiment to be conducted and also special thanks to Prof
Maurice Ndege of Vaal University of Technology for encouraging us to do research in the faculty of engineering.

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