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The deterioration of production schedules during unforeseen disruptions

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In most real-world environments, production scheduling is an ongoing process where the presence of a variety of unforeseen disruptions is usually inevitable, and continually forces reconsideration and revision of pre-established schedules. Many of the approaches developed to solve the problem of production scheduling are often unfeasible in real-world, and near-optimal schedules with respect to the estimated data may become obsolete when they are released to the production lines or shop floor. This paper outlines the impact of unforeseen disruptions that affect manufacturing systems during production, and being able to cope or react to this determines a company's output and profitability. The theories of multifactor productivity and line balancing are employed to determine how disruptions affect productivity output and the result reveals that when disruptions occur continuously with time, the total productivity output decreases as time goes on and, on the other hand, total production time increases and requires more resources to meet the planned capacity demand (PCD).

Keywords: disruptions, uncertainty, capacity requirement planning, enterprise requirement planning

Introduction

Production scheduling is a process of deciding how to commit resources between varieties of possible tasks in an orderly manner in order to achieve manufacturing goals and objectives. Specifically in Cameroon (CMR) tile manufacturing industries, production scheduling problems such as material unavailability, power failures, machine breakdowns, rush orders and others are commonly reported from time to time. As a result, these manufacturing industries or companies rely purely on a number of methods such as dispatching rules, enterprise resource planning, etc. Most of these functions have always been present within these industries but because of different problems like disruptions and the number of jobs that must be executed simultaneously, achieving manufacturing objectives becomes almost impossible.

Production scheduling

Although the first studies of production scheduling started to appear in the 1950s, from the early twentieth century, the work of Gantt (1919) and other pioneers had started to introduce some formal methods into real manufacturing plant operations. However the practical use of scheduling techniques is still meagre. Katragjini (2013) pointed out that King (1976) was one of the first to openly recognise the gap between theory and practice in production scheduling. Scheduling is vital during production. Before the actual formalisation of production scheduling in CMR tile manufacturing industries, there was a time when the industry did not know when work was to start and how it moves through the various manufacturing systems and also when the final product was to be completed and supplied to the customers.

From the above, a decision has to be made at the operational level to minimise disruption of scheduling performance. An example is the decision to be made at each work station on which job should be processed first among the pending jobs.

In actual practice, these decisions are the responsibilities of the shop foremen who react to them based on experience. These disruptions are unpredictable events of various types which may severely impact the performance or output of the production system Aytug et al. (2005) and Muhleman et al. (2004) being able to react to these disruptions or assist decision makers in reacting in the best possible ways are very important issues.

According to Ignall and Shrage (2005), efforts have been made in the past few decades to use conventional optimisation methods to solve production scheduling but these methods have generally been reported as not being reliable in terms of the complexity of the process (Lin and Chang 2001) and when other variables such as random disruptions are included, it even becomes more complex.

Motivation

As previously discussed, a great deal of effort has been spent in the past on production schedules in CMR tile manufacturing industries, assuming there will be no disruptions during the process of execution (i.e. the classical scheduling problems have been considered) but despite the extensive research carried out in this area as stated by Halsall, Muhleman, and Price (2006), many CMR tile manufacturing industries still continue to experience difficulties related to production scheduling and disruption problems.

Disruptions classification

As previously mentioned, the actual performance of manufacturing settings often differs from the planned or scheduled one. The majority of the deviations negatively affect the system performance, leading to deterioration of the production system. The unforeseen disturbances that affect the normal operations of real-life manufacturing settings have been classified into two big categories (Cowling and Johansson 2002; Vieira et al. 2003):

1. Capacity disruptions: i.e. disturbances related to manufacturing resources like machine breakdowns, unavailability of tools, operator's absence, etc.
2. Order disruptions: i.e. job-related disturbances like rush jobs, job cancelations, raw materials shortages, and change in priority, rework, etc.

When disruptions upset system performance or lead to infeasibility, rescheduling is triggered to reduce the impact. Hence, these unexpected events are often defined as rescheduling factors (Dutta 2006). Typical disruptions frequently encountered in manufacturing facilities are, amongst others: machine failures, rush orders, order cancellations, priority and due date modifications, workforce unavailability, material arrival delays, raw materials shortages, delay in transport, rework, variation of process times, variation of set-up times, outsourcing, machine performance deterioration, etc.

Existing research

The aforementioned unexpected events have been analysed in several research studies. Vieira et al. (2003) and Li and Ierapetritou (2008) review in detail rescheduling methods and trends developed to address the problem of dealing with uncertainty in production scheduling. In this section we present a summary of the research papers on rescheduling with uncertainties, focusing especially on single machine, enterprise resource planning (ERP) systems and capacity requirement planning (CRP).

Single machine environment

The single machine scheduling problem is the process of assigning a group of tasks to a single machine or resource with the objective of optimising one or many performance measures. Single machine models are important since practical scheduling problems with more complicated machine environments are often decomposed into sub-problems that deal with single machines. For example, a complicated machine environment with a single bottleneck may give rise to a single machine model. Pinedo (2008) and Bean et al. (2006) present a framework for rescheduling production facilities when disruptions, such as machine breakdowns, tool unavailability, release or due-date changes and order quantity increases, invalidate the original schedule. Their rescheduling strategy is based on matching up with the preschedule after every disruption.

Enterprise resource planning (ERP) systems

Enterprise resource planning (ERP) systems emerged as solutions oriented to manage organisations' resources in an integrated way. They allow the automation of its department's activities, and make information available to users at the right time, supporting more accurately their decision-making needs. However, although the implementation of these systems has brought considerable benefits to users, they don't cover all processes from all industries. Many organisations have recognised this limitation, and consequently felt the need to implement specific solutions to their industry, sector or line of business.

According to Soffer et al. (2003), ERP systems solutions are effective and only have a limitation to static situations where all parameters are known with certainty. These systems have been remarkable in the past for not having adequate capabilities for detailed scheduling and rescheduling solutions when it comes to dynamic production systems with the presence of random disruptions. Another criticism of ERP systems is its hierarchical rigidity and centralising control and management. It assumes that the information should be managed centrally and that organisations have well defined hierarchical structures (Davenport 2000).

Limitations of such partly emphasise the importance of more research on systems that are characterised by random variables or non-deterministic operating systems. ERP systems mainly use the concept of master production scheduling (MPS), which is a tool that assists schedulers to prioritise scheduled work.

MPS groups the actual demand (customer orders) and forecast demand for finished goods stock keeping units (SKUs) or major assemblies. It compares this against the available finished goods stock and scheduled expected receipts from the production schedule. This is done using the concept of time buckets (usually weekly). Any surprise shortages in this process are used to tell the schedulers when they need to create new work orders.

Regrettably there is a major problem with MPS: it assumes that purchase orders and work orders will be completed at the dates that are planned, and has no reconfigurable mechanism for any random disruptions such as a late supply of raw material to a work station that is scheduled for maximum capacity.

Capacity requirement planning (CRP)

According to Heizer and Render (2008), capacity requirement planning (CRP) is an enterprise application system that is used by an organisation, usually in the manufacturing facilities when developing a production plan to estimate capacity fulfilment. It is aimed at measuring, adjusting and establishing the production plan which includes labour, materials and resources required to meet the production plan Howard et al, [19]. Despite the fact that CRP has all these quality and techniques, it also has some serious drawback that are unable to accurately calculate the projected demand, backward scheduling and time buckets.

According to Oden, Langenwalter, and Lucier (2005), CRP uses the concept of time buckets to calculate the projected demand for capacity. Time buckets are useful but have limitations when it comes to calculating available capacity. They do not take into consideration the impact of sequencing on capacity. They also do not have a mechanism to determine the impact on the capacity for the scheduled completion date of an order when raw materials arrive late or any disruption during manufacturing.

Although the CRP problem has received significant attention in the past, it becomes apparent that scheduling tools built in ERP systems do not have the ability to predict downstream consequences of a change of any kind, i.e. they have no tools to help them intelligently prioritise their workload, they have no ability to accurately estimate the promised date of a new order and they have no way to synchronise material and capacity constraints. Given these limitations, the question that arises is how do CMR tile manufacturing industries stay in business? The only way that most of these industries survive is to build-in huge buffers of materials and finished goods. These buffers have cost implications. Furthermore, it is apparent that the methods employed in the past to address the disruption problems did not meet the expectations of the practical problems because they are inflexible (Leitão and Restivo 2008) and some of the researchers concentrated principally on machine breakdowns and new job arrivals (Jain and Elmaraghy 2007; Leitão and Restivo 2008). Various studies on real production systems point out that disruption affecting production systems may occur frequently and randomly, which may make the original schedule obsolete (Leitão and Restivo 2008).

The above mentioned limitations evidently show that CMR tile manufacturing industries are notably affected by random disruptions. Because different CMR tile manufacturing industry-layouts have benefits and as well demerits, it should be beneficial if the effects of disruptions during production are studied on CMR tile manufacturing industries. Furthermore, it is fair to say that there is a need to articulate or propose an approach that should be employed to handle these production scheduling and disruption problems.

Supply chain disruptions

According to Root and Kurz (2008), "If one can actually measure what he is talking about and express it in numbers then it means he has clear information about it", and "You cannot manage what you cannot measure". From an industrial engineering point of view, these statements actually demonstrate why measurements are important, yet it is surprising that CMR tile manufacturing industries often overlook this function. The senior management tends to focus more on measurable performance indicators because of the financial implications they reflect. Measuring the performance of an industry is important, but it is also equally important to measure the implications of disruptions. Unfortunately, many top executives are not comfortable or familiar with disruptions metrics to know how to assess the impact of all these potential disruptions. The ability of organisations to measure and track the impact of random disruptions, as well as changes in trends over time are important tools to effectively manage and control supply chain disruptions. It must be emphasised that supply chain disruptions include all potential disruptive factors from receipt of an order to order shipment – this broad process is referred to as a "value chain"

Existing research conclusions

Diverse strategies and approaches have been developed to cope with several unexpected situations, but most of the work is simulation based, and hence must be interpreted in the context of the specific simulated system. There does not exist a body of standard practices, procedures, and rules when dealing with dynamic and stochastic manufacturing settings.

Methodology

Consequently, systems are subjected to variety of random disruptions and it is important to find out how these disruptions affect the production process during manufacturing. Disruption of a manufacturing system is a clear indication of a system failure which might lead to additional resources to meet required or planned capacity or limited production output.

Manufacturing systems should normally produce products based on market demand (i.e. demand triggers production to commence). Knowing that the amount of raw materials needed to meet the market demands can be obtained, the input functions can serve as a production command to available machines, i.e. machine breakdown during the first stages of production in a flow-line will hold up other machines downstream. The occurrences of disruptions on the manufacturing systems should affect the production of the industries involved. Thus, the initial point of the present paper is productivity. Productivity function can be measured by both input and output functions. Note that the word productivity out-put stands for the ability to produce per given input. Multifactor productivity values are calculated for both ideal production systems without disruptions and for those with random disruptions. The differences between them should enable us to measure how Cameroon tile manufacturing industries systems should respond to various impacts of disruptions, illustrated by:

$$Productivity_{ideal\ state} - Productivity_{impact\ of\ disruption}$$

Multifactor productivity

According to Heizer and Render (2008), multifactor productivity can be calculated using equation (1):

$$P = \frac{Q}{M_{a+M_b+M_c+M_{e+M_m}}} = \frac{Q}{M_t} \quad (1)$$

Where;

P = Productivity function

Q = Output quantity, $I = \Sigma m_t$ is input quantity and should be interpreted as valid for a system that is affected by many production factors as well as systems affected by single factors.

Where

M_a = material, M_b = labour, M_c =Capital, M_e = energy and M_m = Miscellaneous

The input and out-put serve as constrain to production. From equation (1) out-put quantity can be predicted using equation (2).

$$PM_t = Q \quad (2)$$

By differentiating equation (2) using product role, we obtained how the input and out-put varies during production:

$$dQ/dt = M_t \frac{dp}{dt} + P \frac{dM_t}{dt} \quad (3)$$

By redesigning equation (3) with time interval of production of both sides of the expression, the rate of change becomes equation (4).

$$dQ = M_t(t) + P(t) \quad (4)$$

The second differential equation obtained in equation (3) is used to obtain random differential expression (4). The "first integral" solution of the main expression indicates the evolution of output per given time due to disruptions. This solution (i.e. output per given time) is actually the productivity. Thus, during practical application the issue is on determining the fluctuation of the variables "*M*" and "*P*" found in the above expressions.

Negative variable input values are not considered in the present results and, additionally, the increase in input (i.e. increase in input with time) during tiles manufacturing is also not considered. Similarly, the situations that generate negative values of frequency of downtime are not considered. The various constraints that are used are; $a = 0.017$ material/total input, $b = 10^{-6}$ labour/total input and $t = 1.06$ average time/unit produced. These parameters are ideally chosen for trend indicated and are actually limited on different operational needs. The results obtained from this analysis are presented and discussed in the following section.

Results

By using an engineering equation solver and data obtained from the questionnaire and interviews that were administered in the company, the results and findings of equations (1) to (4) are discussed below, followed by respective discussions per graphical depiction in Figures 1a to 1d.

It can be observed in Figure 1a that as disruptions occur continuously with time, the total productivity decreases as time goes on, and Figure 1b indicates that due to disruptions, the actual production time increases.

Using the approach of line balancing to determine the number of workstations, (though not at the level of avoiding bottlenecks), the result of Figure 1c is obtained, which indicates that as time goes on and following continuous disruptions, the number of facilities/resources required should increase. This increase in facilities/resources will account for the time lost due to disruptions so as to increase production rate. The scheduler should reschedule following the trend that is only predicted by the nature of disruption. Figure 1d indicates that the relationship between the amounts of resources that should be rescheduled does not depend linearly on the actual production time.

Conclusion

In this paper, we studied how supply chain disruption affects manufacturing systems during production and a broad definition of what production scheduling is and the various uncertainties. Multifactor productivity and the theory of line balancing was introduced and the results reveal that when disruption occurs continuously with time, the total productivity output decreases as time goes on and on the other hand the total production time increases, requiring more resources in order to meet set or planned capacity demands (PCD).

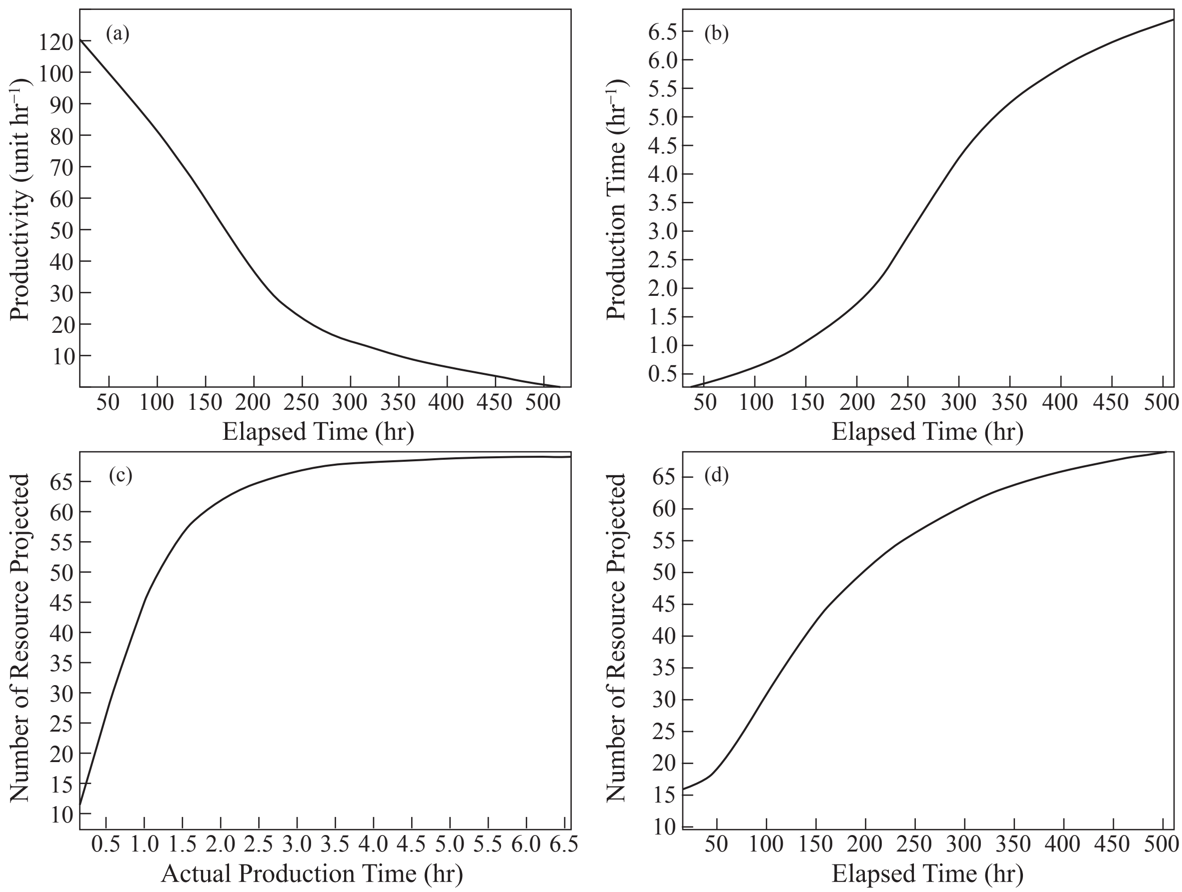

Figure 1: (a) Productivity, (b) Production time, (c) Number of workstation required and (d) Number of resources to meet demand

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