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# Minimising instability on manufacturing systems after random disruption

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One of the major issues in manufacturing systems is to determine how to deal effectively with unexpected disruption during production operation, (e.g. material unavailability, machine breakdown, employee absenteeism, power failure and additional resources, etc.). This paper presents a comprehensive literature review which shows that existing methods and tools offer very few concepts that are sufficient to handle a variety of random disruptions in manufacturing industries. A scheduling model was developed, and random sampling and simulation runs were done to minimise instability of the production system after random disruption. The results indicate that the degree of failure in the production line fluctuates and additional resources are required in order to meet up with planned demand.

**Keywords:** random disruptions, employee absenteeism, scheduling, breakdown

**JEL classification:** E24, J52, L60, N6

## Introduction

Manufacturing operations can be faced with a wide range of uncertainties and being able to cope with these and assist decision makers in reacting to them in the best possible ways is an important issues. Scheduling and disruptions as considered in most literature on manufacturing industries deal mostly with machine breakdowns, late arrival or shortages of raw materials. However, it is unfortunate that this type of study has been isolated, i.e. most of the papers study the negative effects of only one type of disruption. This is completely different from real situations where several types of events may affect the manufacturing process simultaneously.

According to Aytug et al. (2005), there is a pressing need for a practical holistic scheduling methodology after disruptions. Despite the extensive research carried out in this area from reviewed literature, it appears that many manufacturing industries still continue to experience difficulties related to production scheduling problems after disruptions.

With respect to the rescheduling approaches found in the literature, many authors employ mathematical models to generate optimal solutions for the considered rescheduling problem (Muhlemann, et al. 2004; Ingall et al. 2005).These approaches and results however remains well-grounded only within the specific considered problem with its restrictions, and generally cannot be extended to more complex and larger sized problems.

Another gap in the scheduling literature is represented by reflecting the economic performance of the scheduling system only with classical efficiency performance measures such as the makespan, maximum flow time, earliness, tardiness, etc. It is important to point out that, as time goes by, the original schedule become inaccurate and rescheduling actions are needed to address new situations. Consequently, introducing frequent schedule changes can also give rise to additional costs, such as setup costs, material handling costs and storage cost, etc.

### *Production scheduling*

Production scheduling is a process of deciding how activities should be performed in an orderly manner to meet manufacturing objectives and goals. Before the actual formalisation of the concept of production scheduling in manufacturing industries, there was a time when industry did not know when work was to start, how it moved through the various manufacturing systems, or when the final product was to be completed and supplied to customers. From the above, a decision has to be made at the operational level to minimise the effect of disruption on 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.

Disruptions are unpredictable events of various types which may severely impact the performance or output of the production system (Lin and Chang 2001; Halsall et al. 1994). Being able to react to these disruptions and to assist decision makers in reacting in the best possible ways are very important issues.

According to Dutta (1990), efforts have been made in the past few decades to use conventional optimisation methods to solve production scheduling problems, but these methods have generally been reported as not being reliable in terms of its complexity and when other variables such as random disruptions are included, it becomes even more complex (Pinedo 2008).

Manufacturing industries need to deliver consistent and reliable services and products to customers in order to keep their market share and, as previously discussed, a great deal of effort has been spent in the past on production schedules in manufacturing industries, presuming there will be no disruptions during the process of execution. But despite extensive research carried out in this area, as stated by Halsall et al. (2003), many manufacturing industries still continue to experience difficulties related to production scheduling and disruption problems.

According to Dutta et al. (2007), when disruptions upset system performance or lead to infeasibility, rescheduling is triggered to reduce their impact. Typical disruptions frequently encountered in manufacturing facilities are, amongst others, machine failures, order cancellations, priority and due date modifications, workforce unavailability, material arrival delays, raw materials shortage, reworking, variation of process times, variation of set-up times, outsourcing, etc.

Therefore, the above limitations evidently show that manufacturing industries are notably affected by random disruptions and it would be beneficial to study the effects of disruptions during production in manufacturing industries.

## Literature review

As mentioned, a great deal of effort has been spent in the past in generating production scheduling after disruption. A comprehensive reference guide for defining and classifying scheduling and disruption problems was presented by Pinedo et al. (2006). On the other hand, Vieira et al. (2007) and Li and Ierapetritou (2008) reviewed in detail rescheduling methods and trends developed to address the problem of dealing with uncertainty in production scheduling. Below is a summary of the existing literature and concluding remarks on the current literature.

### *Matchup scheduling*

A matchup scheduling procedure that repairs a production schedule when disruption occurs was discussed by Bean et al. (1991). According to the results, matchup scheduling is an optimal approach when disruptions are infrequent enough to allow the system to get back on schedule before the next disruption. Jain and Elmaraghy (2003) also studied the impact of disruptions on schedule execution in a flexible manufacturing system (FMS) but it was limited only to machine breakdowns, and other types of disruption were left out. Jain and Elmaraghy (2007) further reported that of all five selected factors for experimental study, the duration of disruption affects the impact of disruption most significantly. The impacts of disruptions are greater in typical FMSs than in a conventional flow-shop setup, and the presence of machine setups helps reduce the impacts of disruptions. Similarly, Mehta and Uzsoy (1999) present an approach to create predictive schedules that include inserted idle time as a means to reduce the impact of disruptions. Overall, the schedule was deemed robust but did not account for performance measure optimisations such as minimisation of completion times, make-span, and flow time, etc.

### *Flow shop environment*

The following section gives a brief description of the flow-shop environment. In a flow-shop scheduling problem there are $m$ machines and $n$ jobs that have to be processed in the same order on the $m$ machines. An assembly line is an example of a flow shop. Allahverdi (2008) considers a two-machine proportionate flow-shop scheduling problem with random breakdowns and the objective of minimising the maximum lateness. He demonstrates that if breakdowns occur only in the first machine, the longest processing time policy obtains the best results and when they occur only in the second machine, the best policy is the shortest processing time. Zandieh and Gholami (2012) propose an immune algorithm for makespan minimisation in a hybrid flow shop with sequence-dependent setups and machines affected by random breakdowns.

### *Parallel machine environment*

In the parallel machine scheduling problem, there is a set of $n$ jobs that have to be scheduled on $m$ parallel machines. A bank of machines in parallel is a generalisation of a single machine model. Many production stages consist of several machines in parallel. Pinedo (2008) and Vieira et al. (2003) present analytical models that predict the performance of rescheduling strategies for parallel machine systems. They consider dynamic job arrivals and setups between job families. Azizoglu and Alagöz (2005) considered a rescheduling problem for parallel machines with breakdowns. They provide a polynomial-time algorithm to find a set of efficient schedules with respect to two different criteria. Curry and Peters (2005) addressed the problem of nervousness reduction in parallel machine settings under dynamic job arrivals. Lee et al. (2006) addressed the problem of two machine scheduling under disruptions with transportation cost considerations. Ozlen and Azizoglu (2008) provided a branch-and-bound algorithm to deal with the parallel machine scheduling problem subject to random machine disruptions.

### *Existing research conclusions*

From the aforementioned, it is seen that many researchers considered the common problem of rescheduling strategies and approaches mainly in response to machine breakdowns and ignored (or turned a blind eye) to other types of disruption. The current literature points out clearly that disruption as considered by a great majority of researchers is principally machine breakdown in the production line department (Vieira et al. 2000; Herrmann et al. 2006). The only industry-layout extensively studied in the literature is production industry layout, and most of the studies are on machine breakdown, which is a deviation from the realistic situation where several types of random disruptions simultaneously affect everyday production operations. These limitations are exceptions to the current study by the authors and partly emphasise the need research on the topic.

## Methodology

As previously mentioned, the manufacturing setting is important. In this paper we apply standard scheduling methods that will consider only the efficiency of the production systems, based on the prescribed schedule, availability of material, power failure, etc. Throughout this work, we refer to the scheduling before disruption as the on-going schedule – denoted by $H$ – and to the adapted scheduling after a random disruption as a new scheduling – denoted by $H^*$. Our main objective is to minimise the instability of the production system after a random disruption. Knowing that the amount of raw materials needed to meet the market demands, we apply the weighted sum method and multiply every single weighted parameter with the objective.

Therefore, the objective function to minimise instability of the production system after disruption has the following structure:

$$Z = \alpha.B_n(H^*) + (1 - \alpha).I(H^*).A^2 \qquad (1)$$

Where $B_n(H^*)$ and $I(H^*).A^2$ represent the normalisation and instability of the system and are calculated as follows:

$$B_n(H^*) = \frac{D_{max}(H^*) - \min(D_{max}).A^2}{\max(D_{max}) - \min(D_{max})} \qquad (2)$$

In equation (2), $\max(D_{max})$ and $\min(D_{max})$ represent the upper and lower bounds of the system while in operation at the moment $t$.

$$I(H^*) = \frac{S(H^*) - \min(S)A^2}{\max(S) - \min(S)} \qquad (3)$$

Similarly in equation (3) $\max(S)$ and $\min(S)$ represent the lower and upper bounds for instability at the moment when disruption occurs. In equation (3), $S(H^*)$ represent the instability caused by disruption calculated as the total sum of operations whose anticipated starting time is delayed in the new schedule

Please note that the number of operations and disruptions is not constant, since the system is subjected to a variety of random disruptions and in real life, manufacturing operations are continuously altered. The model was run for a period of one month, two weeks, and sample data were collected periodically.

The parameter *e* is used to indicate that altering the starting point of an operation does not affect the stability of the schedule, and it must be taken into consideration that the value of this parameter depends on the geographical location and the desired accuracy level in order to consider if an operation has been affected.

## Results and discussion

An example production situation that requires the application of production scheduling with random disruptions is dealt with and for reasons of confidentiality and the sake of not advertising any particular company, the name of the company whose current data has been used will remain anonymous. Without loss of generality and assume that all the workstations operate scrap-free such that the time per workstation or demand per workstation is the same for all the workstations along the production line, a random sampling method and simulation model run are shown in Table 1 and Figures 1 to 3. The results and findings of equations (1) to (3) are discussed below.

Thus, the percentage load that indicates the degree of failure in the production line is expected to fluctuate. This is illustrated in Figure 1 and having a knowledge of "excess resources" requires further help in balancing the incapacitated production lines or disrupted workstations.

**Table 1:** Workstation operational characteristic/disruption

| Operation | Time Standard (Minutes) | Downtime (Minutes) | Failure Rate (F) |
|---|---|---|---|
| Loading | 0.311 | 32 | 91 |
| Mill  flat surface | 0.632 | 45 | 81 |
| Mill  flat surface | 1.321 | 23 | 25 |
| Mill curves | 0.532 | 47 | 91 |
| Drill holes | 0.212 | 10 | 0.4 |
| Loading/packaging | 0.734 | 17 | 0.21 |

Usually disruptions propagate in the production system, causing downstream damage in addition to direct impacts, and reaction strategies will be incomplete unless all affected disrupted production lines are taken into account by identifying and evaluating both direct and partial disruptions. Figure 2 shows that, over the period of 10 000 minutes, the production line is running under normal condition without any disruption. But after 11 000 to 12 000 minutes, an unforeseen disruption emerges causing the total production out-put to drop drastically.

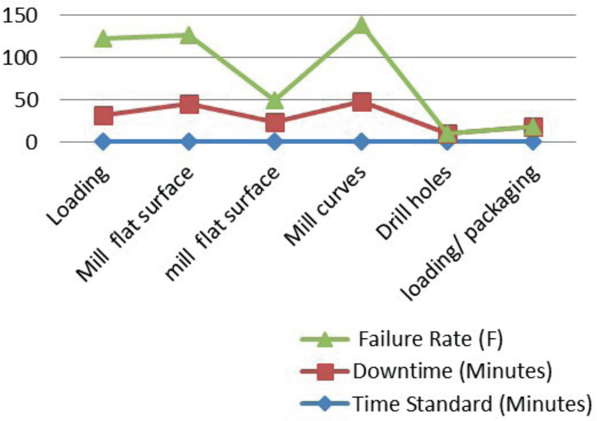

**Figure 1:** Disrupted manufacturing operations

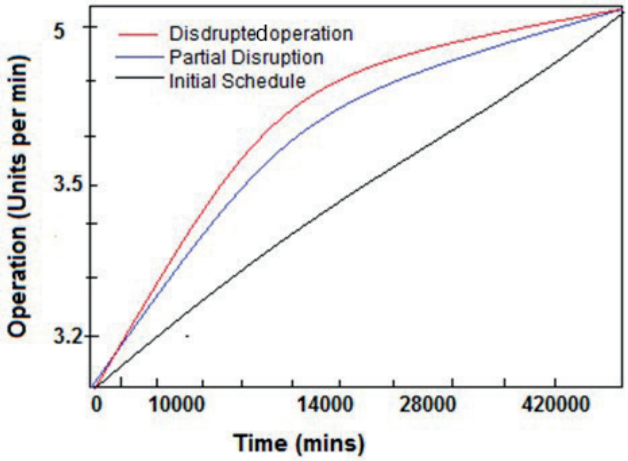

**Figure 2:** Production operations

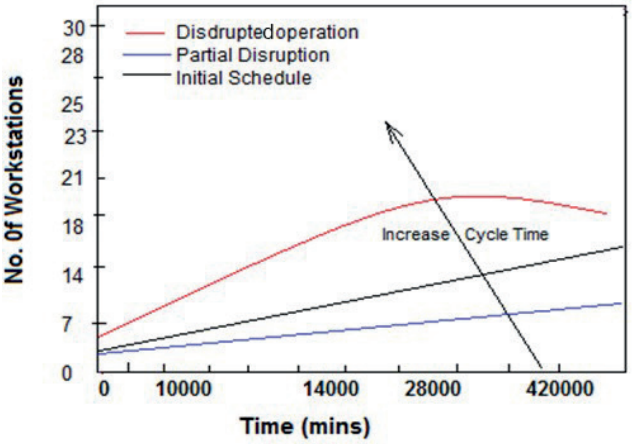

**Figure 3:** Increased production cycle time

This entails the need for production facilities to be adjusted in order to deal with the changed conditions. Figure 3 shows that in order to deal with the change conditions caused by the unforeseen disruption, the number of work stations needs to be increased in order to meet up with initial demand. This also causes the cycle time to increase due to time lost during the disrupted period and also to account for the productivity lost.

## Conclusion

In this paper, our initial part of the work presented a brief review of scheduling literature, evidencing the lack of standard methodology when dealing with a stochastic manufacture setting and the existence of a gap between theory and actual real-life production scheduling and random disruption problems. We have addressed manufacturing operations under different types of random disruption, and the result reveals that as time goes on, the production systems are affected by a variety of disruptions, which in response require other operational strategies to overcome them to meet planned production output.

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