Flow disturbance analysis in workshops with high reworks rate

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ABSTRACT: Companies with high reworks rate have a real problem of flow management. Despite methods in place leading to minimize the number of reworks, they often must implement palliative solutions to manage disturbed flows. We propose in this paper a diagnostic approach based on reworks and flow disturbance indicators to enable them to view the disturbing status of their workshop. This work is a part of a more global work which aim is to develop a flow management control system based on product driven control concept and real-time indicators chosen from those presented in this paper.

KEYWORDS: reworks, flow disturbance, indicator, simulation

1 Introduction

Some companies present an unavoidable high reworks rate as shown with the lot of works pursued to include reworks in methods such as Economic Production Quantity (EPQ) optimization [2], production run time optimization [3] or replenishment policy [4]. Even if there are a lot of methods trying to decrease reworks rate, companies have to dealing with. Quality remains a priority number one, especially when there is an increased of customer demands in a context of difficult mastery of manufacturing process (unstable over time as example). The flow disturbances due to reworks have been analyzed since a long time by many authors [6]. But this problem was often studied only on simple or particular cases [8, 11]. Moreover, indicators for analyzing tested situations are often arbitrarily chosen without taking into account the different points of view. However in our meaning, simulation can help to understand each point of view of each indicator token into account. The master objective of this work is to bring to this type of companies a decision support based on several indicators to enable them to better understand the impact of their reworks rate on the complexity of their physical flows on the shop floor. That leads them to be able to anticipate the impact of quality drifts on flow control problems and to react quickly and well to decrease it thanks to cartography of the real-time state of their workshop. After presenting in more detail the purpose of this paper, possible indicators and their characteristics to handle reworks rate and flow disturbance are listed. Then, the simulation model and the selected test scenarios to compare their behavior rate are explained.

2 Background and issues

The most relevant approaches to understand and control Quality [7] is based on manufacturing approach. It combines conformance to customer requirements and the "right the first time" concept to reduce costs and ensure quality. Non-quality products can be the result of a higher than usual customer requirement, which may occur during the conquest of new markets (export ...). In this case, processes are well mastered but a higher quality level is required to reach new customer requirements. Nevertheless, non-quality may also result from unstable manufacturing process or process drift. Many companies working for the luxury market face with this problem because quality requirements lead to be close to technological limitations of the manufacturing process. Because products are expensive, only two reactions are possible to fix the non-quality product detected at the x^{th} workstation on the existing X workstations:

- Case 1 (Repair) : Sending it to a dedicated workstation W_{spe} leading to:
  - Two new flows created: $W_x \rightarrow W_{spe}$ et $W_{spe} \rightarrow W_{x+1}$
  - Maximum number of additional flows: $M_{apf} = 2 . N_{spe}.X$
    with N_{spe} the number of workstations dedicated to repairs

- Case 2 (Rework): Sending it to a previous workstation W_{x-y} leading to:
  - Only one new flow created: $W_x \rightarrow W_{x-y}$
  - Maximum number of additional flows: $M_{afp} = \sum_{i=2}^{X}(i-1) = \frac{X}{2}(X-1)$.

In practice, both cases have sometimes to be considered at the same time but this paper focus on case 2. We call reworks all products repaired by sending it to a previous workstation. If reworks rate is fluctuating, arising disturbances will also be fluctuant and unpredictable, which complicates production control. It is recognized that reworks affect the performance of system productivity [5]. COQ (Cost of Quality) method is appeared in the 50s thanks to the concept of the ghost factory which is a workshop parallel to the official workshop with the mission is to repair the defects of the official factory [6]. It represents 40% of the production capacity of the official factory. The first standard on the subject appears in France in 1986 (X 50-126) to evaluate the costs of non-quality [1]. A statistical analysis relative to one workstation problem points out the oscillatory phenomenon [11] that is also mentioned in other works where the aim is to evaluate performance on a workshop with multiproduct type [12]. The production flow disturbance by reworks is especially important if reworks emerged downstream in the production process [8]. So, for the production control, we have to follow and maintain a low reworks level to be sure to simplify the initial piloting problem [9]. However, even reducing and stabilizing the reworks rate, the resultant disturbance on the flow remains consistent and makes scheduling difficult.To evaluate the reworks rate in a company, an indicator that counts the number of defects is often used. Nevertheless, when reworks rate is growing, the probability to repair several times the same product is growing, too. So how to count these products becomes a critical issue and it is difficult to make a direct link between reworks rate and flow disturbance. As previously said, this paper is a part of a global work which aim is to analyze, compare and identify relevant indicators to measure the reworks impact on workflow disturbance. These indicators are presented in part 3.

3 Indicators determination

3.1 Selection of possible indicators

Two kinds of indicators allow to measure reworks rate and product flow disturbance. For reworks, there are global (at the company scale) and local (related to the most stringent workstation, generally the bottleneck) indicators defined bellow:

- N_{config} is the number of reconfigured rooting sheets relative to normal ones. It is independent of the number of disturbed products if we don't work in unit lot size.
- N_{defect} is the number of products which have had at least one defect relative to expected products to make. It takes into account the exact number of disturbed products. There is no consideration of products repaired more than once time. There is a weakness due to the fact that some defects may not cause disturbance of the sequence of the manufacturing program but just a longer production time. In the case of a model with lot size unit, $N_{defect} = N_{config}$ because the number of lines reconfigured is directly equal to the number of products on which we have detected at least one defect. Effectively, detection of a defect involves repetition of one or more operations. Whatever the situation: $N_{defect} \leq P$.
- N_{work} is the number of products actually processed on the workstation relative to expected products to make. It is very simple to measure but we have to note that it cannot differentiate if added operations have been made on several products or on the same product. Moreover, N_{work} is always exceeding 100%.
- RO_{SD} and/or RO_{AV} is the Operation Ratio that corresponds to the number of real operations compared to what was expected in the routing sheet. As RO is relative to a specific product/lot, it is recommended to take into account the average/mean (AV) and/or standard deviation (SD). RO represents both the rooting sheet disturbance and the level of this disturbance. If any defect exists for one product, its RO is equal to one. It is more difficult to measure than previous indicators.

Similarly, there are possible indicators to measure the workflow disturbance:

- N_{WIP} is the work in process (average or max). It is important to note that a well distributed work in process is not necessarily penalizing, even if it is heavy. Note that it is not useful on one workstation because it will be equal to N_{stock}.
- N_{stock} is the stock level upstream an important workstation (average or max).
- C_{max} is the time to complete all the production. Commonly used in scheduling problems, it is equivalent to the end production date of the last product. Two schedules can give the same C_{max} but with a very different customer service rate.

- T_w is the waiting time.
- R_{max} is the maximum delay. Depending on the case, be an hour late is sometimes equivalent to be a week late, and sometimes, late penalties are too heavy.
- N_{late} is the number of late products.
- T_{break} is the out of supply time on the bottleneck workstation. It can be measured only on models with several workstations.

3.2 Model presentation

The Petri net presented on Fig. 1 has been implemented in ARENA to analyze the impact of an increase of each reworks indicator on a manufacturing process. Despite the apparent simplicity of this model, model reduction often leads to summarize the problem with a one- or two-workstations model [10]. The two machines have the same production rates. There are others similar works in literature that performs a scheduling on a two-machine problem [7]. The lot size is unitary and each product is directly transferred to the next workstation, not involving additional time corresponding to the pending end of batch before transfer. It avoids the problem of splitting lots to remake only a part of product [11].

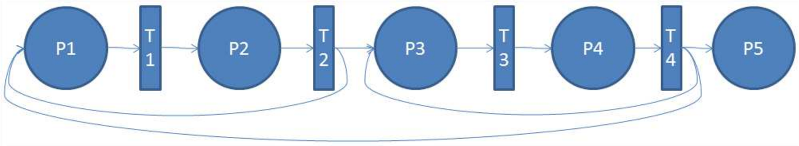


Fig. 1. Petri net representing our problem and implemented in ARENA

- P1: Wait in queue before workstation 1
- P2: Process on workstation 1
- P3: Wait in queue before workstation 2
- P4: Process on workstation 2
- P5: Finished state
- T1: Workstation 1 available
- T2: Operation end on workstation 1
- T3: Workstation 2 available
- T4: Operation end on workstation 2

Usually, different scenarios are established to test several types of workshops. In our simple case of one or two workstations, combinations are limited. Being able to apply several different piloting rules will allow to test different scenarios without having to complicate the workshop. Priority rules most commonly used are FIFO (First In First Out), EDD (Earliest Due Date) or the critical ratio. EDD is chosen in order to allow permutations between reworks and normal products in queues. The due date required for the implementation of the priority rule EDD was determined for each product to represent a "normal" situation with low reworks rate leading to no delay. Probability of reworks occurrence are explained on (Fig. 2) with the following particularity:

$$\begin{cases} T_{reworks}(M1 \rightarrow M1) = T_{reworks}(M2 \rightarrow M1) + T_{reworks}(M2 \rightarrow M2) \\ T_{reworks}(M2 \rightarrow M1) = T_{reworks}(M2 \rightarrow M2) \end{cases}$$

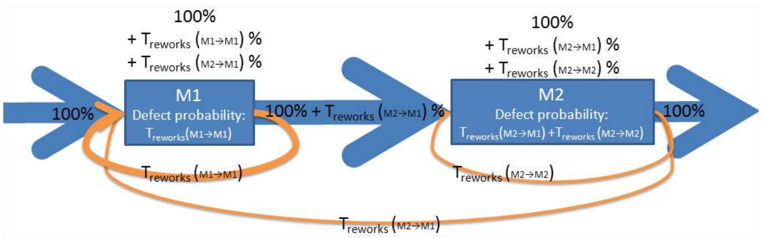


Fig. 2. Probability of reworks occurrence

To have different vision of reworks with unitary lots, only N_{defect}, N_{work}, RO_{AV} and RO_{SD} are tested. If there is no variability in the model, our indicators are dependents and it is possible to express them with a mathematical formula. But, in reality, variability involves disturbances (ex. Forester Effect). This variability is included in the model by using normal distribution for the product arriving in the first queue, the processing time on workstations and the probability of defect occurrences.

4 Analysis and results

4.1 Analysis of reworks indicators.

Two scenarios are tested: one and two workstations. All graphs are relatives to the reworks rate R_R applied on workstation(s). N_P products are send through the model.

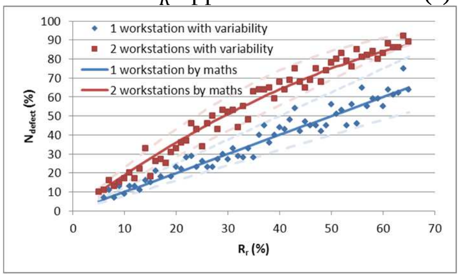


Fig. 3. N_{defect} and its dispersion based on reworks rate for 1 and 2 workstations

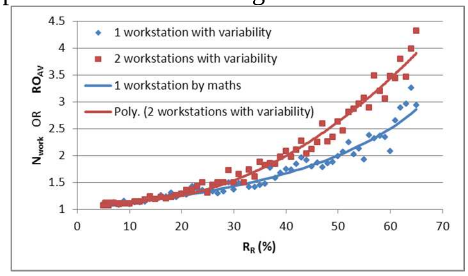


Fig. 4. N_{work} on both workstation based on reworks rate for 1 and 2 workstations

By mathematical definition, $N_{defect}(1W) = R_R$ and $N_{defect}(2W) = R_R \times (2 - R_R)$ (Fig. 3). The dispersion observed with model variability seems to be different between one (only increasing) and two workstations (increase then decrease). This indicator offer a view of the capacity to make product right the first time.

By definition, $N_{work}(1W) = \sum_{x=0}^{\infty} R_R{}^x = 1 + \frac{R_R}{1-R_R}$. Dispersion is also due to variability in the model. With two workstations, the formula is already difficult to determine but the same dispersion exist, too. With one workstation as with two workstations, RO_{AV} is directly equal to N_{work} (Fig. 5). These indicators offer a view of the volume of load on the workshop. As the number of operations increase in a non-linear mode with the reworks rate, it is important to work to decrease the reworks rate.

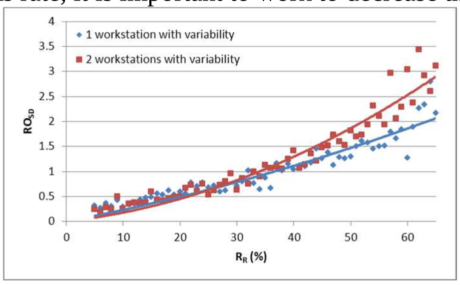


Fig. 5. RO_{SD} based on reworks rate for 1 and 2 workstations

RO_{SD} offers a view on the predictability on the respect of deadlines. Higher the reworks rate is, more difficult is to predict the number of necessary operations and so the product completion time.

There are many ways for representing the reworks on the workshop. The most appropriate choice to use the indicator may depend on the type of workshop but also the desired view. A combination of several of them can also give a more comprehensive understanding from different perspectives (capacity to make product right the first time, volume of charge on the workshop and predictability on the deadlines respect).

4.2 Analysis of workflow disturbance indicators

The same model is used with two workstations but with two other scenarios: EDD and FIFO. The stock upstream the bottleneck machine 1 N_{stock} (Fig. 6) seems to be a good indicator of the disturbance flow as well as work in process N_{WIP} (Fig. 7). However, these two indicators are not able to differentiate EDD from FIFO. The similarity between these two indicators is also explained by the one machine model where N_{stock} is equivalent to N_{WIP}. Theoretically, R_R increasing tend to get some kind of system saturation. In practice, this still represents more pieces to handle, store, manage simultaneously, which negatively influence all production indicators. C_{max} indicator, commonly used in scheduling, has the same behavior that T_W. C_{max} and $T_{W_{av}}$ are also unable to differentiate our scenarios but $T_{W_{max}}$ can. It seems that, in relation to $T_{W_{max}}$, EDD rules application appears more effective than FIFO rules.

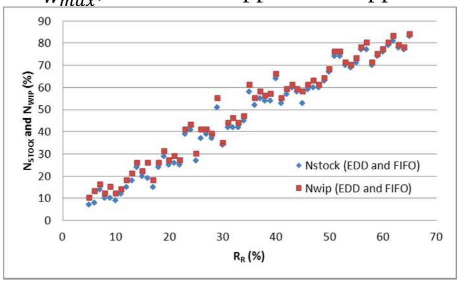


***Fig*. 6**. N_{stock} and N_{WIP} based on reworks rate for 2 workstations

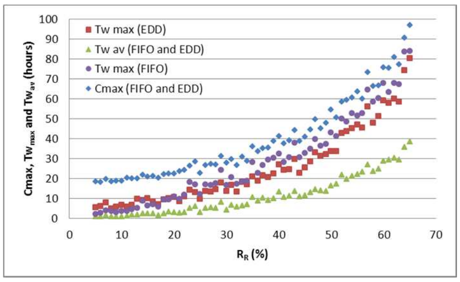
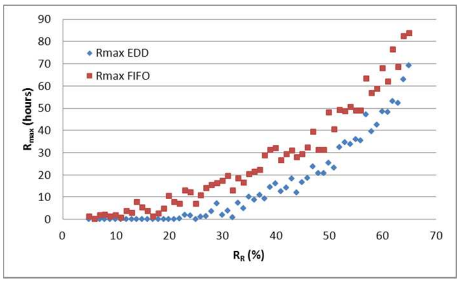
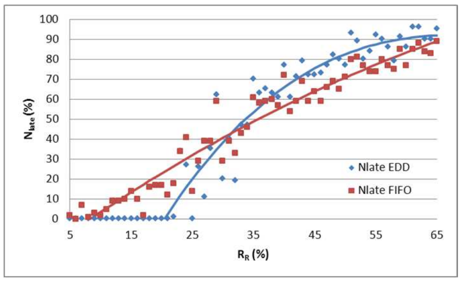


***Fig*. 7**. C_{max} and T_W based on reworks rate for 2 workstations

N_{late} and R_{max} are able to differentiate our scenarios (Fig. 8 and 9). The FIFO priority rule generates delays even with a very low R_R while the EDD rule generates delays when R_R increases. So it seems to be better to apply EDD at low reworks levels. However, when exceeding a certain reworks level to be determined according to the workshop modeled, either seeking to minimize the maximum delay and keeping the EDD rule, or seeking to minimize the number of late and applying the FIFO. This rule change may be an example of the functions of our support system workflow management. These two indicators seem particularly useful for controlling the system by the rules.



$\boldsymbol{Fig.8}.\ R_{max}$ based on reworks rate for 2 workstations



$\boldsymbol{Fig.9}.\ N_{late}$ based on reworks rate for 2 workstations

Flow disturbance is also a concept difficult to represent because it exists a lot of point of view. Depending on management objectives, some indicators alone are not appropriate. For example, it is impossible to differentiate the EDD and FIFO rules if we consider only N_{WIP}, N_{stock}, C_{max} or T_W. The best solution seems to be a combination of indicators. The latter figure shows that the same rule for controlling the workshop is not necessarily effective in all cases of running of the workshop. This therefore shows the usefulness of our support system. Flow management will be able to offer the user the best rule to use based on selected indicators for monitoring the workshop.

5 Conclusion and outlook

Flows repairs due to reworks disturb production consistently. This is largely confirmed by the literature but rarely studied in depth. To develop a system for assisting the production piloting for companies with high reworks rates, we propose a thorough study on reworks and flow disturbance indicators. There are several ways to control reworks for companies. We must be aware of the different possible points of view and their advantages and drawbacks. In this paper we propose a new indicator, the Operation Ratio that has the advantage of combining the manufacturing program disturbance with the level of disturbance and appears correctly reflect the reworks rate in the workshop. Flow disturbance is also a difficult concept to measure. The usual indicators offer only a single view of the flow disturbance. If we want to have a global view, we need to work on a combination of these different indicators. As perspectives, we have to validate our analysis on a real scale industrial case, which will bring our work to a realistic level. We hope to develop a behavioral mapping of the workshop in order to locate it in real time and make the right decisions on the piloting rules.

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