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# Performance evaluation of several configurations in operation flexibility

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**Abstract** – Assessing the performance of a manufacturing system is an obligation in the high competitive economy. On one hand, the logistic operating curves (LOC) have been well developed, defining some key performance indicators (KPI) and on the other hand, the operations flexibility of a manufacturing system is a type of flexibility that has been measured by the number of the ways a production of a single product or product mix can be done. In this work, we propose an assessing metric to choose the best operation flexibility scenario. Defining a good metric using the normalized operating curves and simulation modeling is our target in this study. The time remained to transform Work In Process (WIP) into finished goods is given as a good metric and as a decision support tool regarding the strategic values of a manufacturing company.

**Keywords:** LOC, time remained to transform Work In Process, operations flexibility, manufacturing performance.

## 1. Introduction

Many metrics are considered in assessing a manufacturing system; we can have some structural criteria of the system (e.g. operation flexibility, technology levels). The flexibility of manufacturing system has been categorized and the measures of different types of flexibility have been detailed. Reference [1] identifies thirty four items affecting manufacturing flexibility and presents instruments to measure them.

The operations flexibility is defined [2] as 'the ability to produce a given set of part types, each possibly using different material in several ways'. Then, the operations flexibility defines the number of ways we can produce a single product or product mix [3] with the considered system.

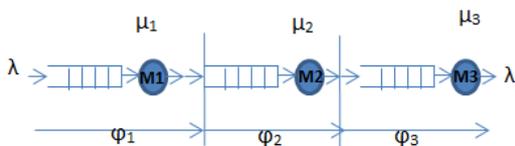
A tool to compare several configurations of operation flexibility or general comparable systems is needed. And this will be the subject of our work.

Firstly, we present the normalized operating curves that are extended using value time remained to transform a quantity of WIP into finished goods metric noted T. This latter is defined in the third section. In the fourth section we present the serial line studied in several configurations of operation flexibility. In the last section, we will consider some further applications of measuring value time in WIP to compare bigger systems.

## 2. Normalized Operating Curves

In logistic operating curves some several curves can be scoped in the same schema helping the decision maker to choose the appropriate tradeoff of different objectives: throughput rate, flow time, schedule reliability, cost [4]. The normalized operating curves were developed to assess and compare several different systems.

For a serial line, [5] define traffic intensity  $\rho_{line}$  and a flow factor  $F_{line}$ , for deriving the normalized operating curve. In figure 1 we present an example of a serial line with:  $\lambda$  the arrival rate,  $\mu$  the process rate and  $\varphi$  the flow time.



**Figure 1.** Serial production line of stations with different service rate

The traffic intensity  $\rho_{line}$  is calculated as follows:

$$\rho_{line} = \frac{\lambda}{\min_i \{\mu_i\}} \quad (1)$$

The flow factor  $F_{line}$  is defined as:

$$F_{line} = \frac{\varphi_{line}}{\sum_i \frac{1}{\mu_i}} \quad (2)$$

The normalized operating curve of a system of serial line of servers is a function of the flow factor  $F_{line}$  of the traffic intensity  $\rho_{line}$ .

## 3. Value time metric T

In this work we propose another metric having a dimension of time. We define it as the value time remained to transform the quantity of WIP, existing in the different queues, into finished goods. We note this time by T.

To calculate T some measures need to be taken from the production line. The mean quantity of WIP in queues is measured for a reference period of time. Then each quantity is multiplied by the time remained to be processed in downstream of the production line.

If we treat the example of figure 1 to calculate T, three quantities in three queues are considered ( $Q_1, Q_2, Q_3$ ) of the three servers.  $Q_1$  is multiplied with the sum of the three processing time of the three servers in downstream to obtain the process time remained to have the quantity  $Q_1$  as finished goods.

$$T_1 = Q_1 \times \left( \frac{1}{\mu_1} + \frac{1}{\mu_2} + \frac{1}{\mu_3} \right) \quad (3)$$

We expand the procedure for  $Q_2$  and  $Q_3$ .

$$T_2 = Q_2 \times \left( \frac{1}{\mu_2} + \frac{1}{\mu_3} \right) \quad (4)$$

$$T_3 = Q_3 \times \left( \frac{1}{\mu_3} \right) \quad (5)$$

T is the sum of  $T_1, T_2$  and  $T_3$ .

## 4. The Operation Flexibility of a Serial Line

We study the performance of several operation flexibility scenarios of a serial line.

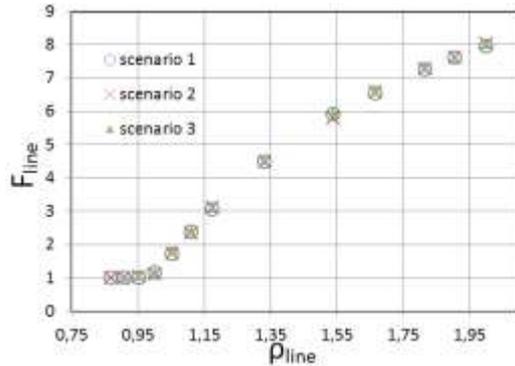
In our case, we study a multi stage system with a special case of single machine at each stage and processing a single item: Serial line with three machines: one machine as a bottleneck with a stochastic process time distribution (Norm(2; 0.1)) and the two other machines are similar characterized by the process time Norm(1; 0.1).

We can have three configuration of the system as shown in table 1.

**Table 1.** The three scenarios studied.

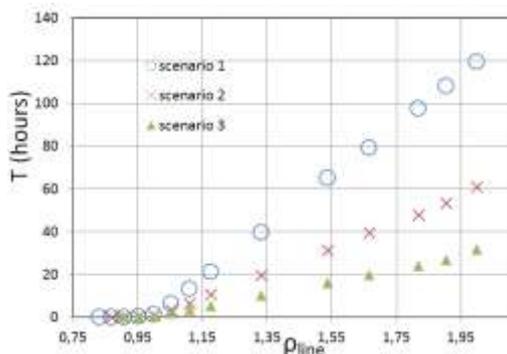
Scenario	Order of machines in the stream line
1	M1-M2-M3
2	M2-M1-M3
3	M3-M2-M1

A simulation (discrete event simulation) is realized for the three scenarios of the serial line. In our case the input flow is a stochastic process (Norm(X; 0.1)). The results of the simulation are shown in figure 2.



**Figure 2.** Normalized operating curves of the three scenarios of operation flexibility

We can notice that the normalized operating curves are superposed. This tool of evaluation of different systems cannot give an indication about the difference between the three scenarios so we introduce the T metric to show the difference between the three scenarios. This time T is calculated as already detailed in section 3 and the results presented in figure 3 as T as a function of the traffic intensity  $\rho$  line.



**Figure 3.** The metric T as a function of traffic intensity for the three scenarios.  $T = f(\rho_{line})$

The first scenario show a much time remained T as the traffic intensity get greater. The second and the third scenarios show respectively an inferior remained value time T.

The choice of the appropriate scenario of production will depends on the company production policy and the general strategic values.

Choosing the high value of T (like scenario 1) is the decision of keeping WIP in the upstream. This choice is taken in case of the willing to reduce the

investment in the WIP: The value of the WIP is lower in upstream than downstream.

Choosing the low value of T (like scenario 3) is the decision of keeping WIP in the downstream. This choice is taken when the bottleneck machine is very expensive and the value added of this machine is high. Also when high delivery reliability is needed, this second strategy is needed (as we have little time to transform the WIP quantity to finished goods, we can make easier the right decision about the capability of delivering a certain quantity to customer).

## 5. Conclusion

Through this work, we introduce the “value time remained to transform WIP into finished goods” metric noticing the insufficiency of the normalized operating curves to evaluate the case of operations flexibility scenarios in a serial line.

Using this metric as a function of the traffic intensity is very useful as a tool to compare some complex systems with multiple stages.

Since the supply chain is a big system, it contains long cycle times. Besides the operations flexibility can exist in a supply chain [6], so evaluating different scenarios or systems with the curve ( $T = f(\rho)$ ) can be very useful for the supply chain scenarios evaluations.

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