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Performance evaluation of layout designs by throughput rate and operational complexity

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Abstract

Even though several researches have focused on exploration of mutual relations between batch size and throughput, there is still relevant research to be done and considerations to be made as organizational problems in manufacturing are not irreversible. That is because practitioners want to know how to optimize input parameters to reach acceptable objectives. The main goal of this paper is to show easily-applicable procedure to analyse mutual relations between batch-size, throughput rate and complexity via a simulation. The exploration has been performed by an analysis of batch sizes´ impact on performance of production processes organized into two different basic designs – product and process layouts. Moreover, impact of process parameter changes on complexity of production process will be treated.

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Keywords: Batch size; Throughput; Cycle time; Simulation; Entropy-based complexity

1. Introduction

Decisions about layout design play an important role in ensuring that manufacture of typical group of products will be managed effectively and efficiently to achieve the company goals. We consider two basic types of layouts: process, and product. The process layout is used primarily in job shop manufacturing systems, and product layout is composed mainly for higher production volumes in flow lines.

The best way to verify and validate the proper layout option can be achieved through simulation methods. For this purpose, the Tecnomatix software plant simulation will be applied. As the paper title indicates, the two indicators were selected to assess layout designs' performance when basic product characteristics are available. They are throughput rate and operational complexity. The throughput rate will be calculated using two methods. The first method, so-called classical approach uses the Little's law and is calculated by the simulation software itself. The second method has been developed by Yu and Efshtathiou [1] and uses probabilistic approach.

The essence of the explorations was to find answers to the following research questions:

RQ_1: How transformation from process layout design into product layout design affects throughput rate of a manufacturing system?

RQ_2: How transformation from process layout design into product layout design influences operational complexity of a manufacturing system?

Finally, based on results obtained from the simulation experiments, decisive findings are formulated and discussed.

2. Related works

Complexity of manufacturing system can be either static or operational [2]. Static complexity can be defined as topological function for the system, connections, product and component variety. Operational complexity is understood as unpredictable states of the system behaviour in time. The notion 'complexity' is divided into time independent and time dependent [3]. A comprehensive review paper has been recently published by Efthymiou et al. [4]. Various measures and models have been developed so far. For example, Frizelle

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and Woodcock [5] proposed approaches to measure static complexity using the measurement of entropy. Shannon [6] formulated the very first measure of information content in computer science called information entropy in 1948. Flood [7] stressed out that complexity is related to both, system and people and can be evaluated by a number of system elements and relations among them. According to Strogatz [8], structural properties of complex networks are the most basic issues since they always affect the function. Zhang [9] showed that a transformation of a job shop manufacturing system into a cellular manufacture reduces the structural complexity by changing production mode.

Similarly as in the case of manufacturing complexity issues, there are many studies focused on relations between batch sizing and throughput rate. For some of them, the content is quite close to the research dealt in this paper. Benjaafar and Sheikhzadeh [10] examined, among other problems, the impact of batch sizing decisions in a multi-item production system on throughput rate. Koo et al. [11] explored possibilities to determine batch size at a bottleneck machines in order to increase their throughput rate. Meng and Heragu [12] proposed the concept of a relative batch size for the purpose of modelling the effects of batch size on throughput rate in discrete manufacturing system via an open queuing network.

3. Description of performance measures

Selected performance characteristics of a production process such as the throughput rate of parts per minute and operational complexity of production process are described in the following subsections.

3.1. Throughput rate

Throughput rate is the total amount of items processed or produced by a system over a defined period of time. Throughput rate can be calculated in two different ways. One of them (denoted as probabilistic approach) is based on probability of machines' states and their working rates. Then, throughput rate of a manufacturing system is expressed as follows [1]:

$$Throughput\,rate = \sum_{j=1}^{s} w_j \cdot P_j \;.\; 100\%, \quad (1)$$

where: w_j - working rate; if state is idle then w_j=0; if opposite w_j=1, P_j – probability of a system being in j-state.

When calculating the throughput rate, it is necessary to consider also how machines are organized. Then we need to differ between parallel or serial layouts of individual machines. If the layout is serial (see Fig. 1), then the following formula to obtain the throughput rate of a system exists:

$$Th = Th_1 \cdot Th_2 \cdot \ldots \cdot Th_n \,, \quad (2)$$

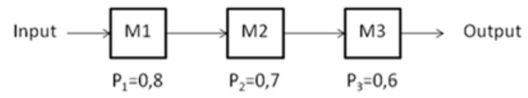

Fig. 1. Serial layout scheme.

where n represents number of machines.

Using the given values of machines' state probabilities, the value of throughput in this case is as follows:

$$Th = (0{,}8 \cdot 1) \cdot (0{,}7 \cdot 1) \cdot (0{,}6 \cdot 1) = 0{,}336 \,.$$

This is a system, in which all the machines are in series and they all have to work for the system to work. If one of the machines fails, the system fails also.

In the case of parallel machines' layout as in Fig. 2, the following equation can be used:

$$Th = \left[1 - \left(1 - Th_n\right)^k\right], \quad (3)$$

where k is number of machines in parallel.

In this specific case using the scheme in Fig. 2, the value of throughput equals the following:

$$Th = \left[1 - (1 - 0{,}8)^5\right] = 0{,}992 \,.$$

For the second way of throughput rate calculation by the classical approach, results are generated by the software using the Little's law.

3.2. Entropy-based operational complexity

Complexity of a manufacturing system based on the Shannon´s entropy is expressed by the following equation [6]:

$$H_s = -\sum_{i=1}^{N} P_i \cdot \log_2 P_i \,, \quad (4)$$

where: N – number of system states; P_i – is probability of system being in state-i.

Equation (4) can be adopted to determine the overall structural complexity of numerous systems by the following formula [5]:

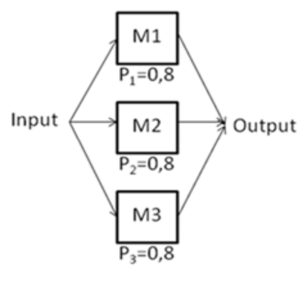

Fig. 2. Parallel machines' layout.