DETERMINATION OF THE COST OF INTERNAL MANUFACTURING FLEXIBILITY - COMPARATIVE TEST RESULTS FOR WCM AND XPS SYSTEMS

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Abstract

Attaining the highest level of manufacturing system organization requires low-cost structural flexibility, associated response speed and adaptability to the changing market and technological environment. The low-cost flexibility of a manufacturing system is a combination of organizational elements that leads to the balancing of the system internal flexibility and leanness levels. A basic problem in the balancing process is that both the flexibility and the leanness of manufacturing exclude each other (i.e. what is lean cannot be flexible, and vice versa). This study analyzed the levels of the internal flexibility in two ways for improving manufacturing systems: based on the world class manufacturing approach (WCM) and based on the x-manufacturing approach (xMS). Estimating the cost of internal flexibility will allow for the subsequent statement of their leanness costs and thus enable the development of low-cost flexibility.

Keywords: Internal flexibility, WCM, xMS

1. I INTERNAL MANUFACTURING FLEXIBILITY

Manufacturing flexibility (most often considered as economic and operational) is a complex, multidimensional category that can be defined in different ways and thus differently interpreted [1-4]. Literature on the classification of production flexibility, for example [5-7] (both in terms of attributes, functions, etc.), and its management, e.g. [8,9] oganization. The types, levels, strategies, and dimensions cited in the literature, e.g. [10,11] make it unequivocal. An analysis of this definition shows that the flexibility of manufacturing [12] can be understood as an ability to react to change. In other words, a purposeful and economic maintenance of reserves for specific resources to be used at any convenient time (e.g. when an opportunity arises - the condition for using the opportunity is, inter alia, to have resources available and, actually, their excess or, at least have access to them). Manufacturing flexibility is also the ability to react [13] to the occurring uncertainty in such a manner that either will maintain or increases the system's parameters in the area of realization and functioning cost relating to the operational level (the level of the segment/module and its less complex parts) [11]. In manufacturing systems, an increase in flexibility at the operational level (so-called internal/operational flexibility), which is associated with the scope of its possibilities to change in the area of the resource, process, or production plan [14]), is most often achieved as a result of the increase in: resource flexibility (closely related to resources occurring in the manufacturing system, primarily material ones, and the possibility of changing/replacing them, as well as their redundancy), process flexibility (associated with the possibility of changing the course of manufacturing processes within the existing structure) and planning and control flexibility (related to the ability to configure alternative production plans within the defined product line group, used in specific situations). Flexibility on the internal level may apply to all manufacturing system areas; most often, however, the following are distinguished: the product area (e.g. constructional or technological flexibility), the technology area (e.g. machinery or route flexibility), and the area of the system and its organization (e.g. product line, plan or cooperation flexibility). Due to its operational nature, flexibility is measurable, and the formulas for its calculation and its necessary level are provided in numerous studies, e.g. [5,15,16]. In the compilation to calculate internal flexibility, the formula was chosen based on cost and time.

2. COST OF INTERNAL MANUFACTURING FLEXIBILITY

According to definition, the costs of internal flexibility is the sum of the costs of: resources necessary for the ongoing execution of tasks, as well as their redundancy, real processes and their alternative (virtual) flows (the costs of operations possible to be taken into consideration) and preparation of plans and ongoing flow control, along with their possible modifications. Adapting this definition, it is possible to specify the formula for determining the cost of internal manufacturing flexibility, which are a weighted costs average derived from the change of resources (Kz), processes (Ko) and production plans (Kp). In practice, all necessary data can be easily acquired or estimated, provided that the appropriate costing is used. A dedicated costing method for determining the internal flexibility cost is activity-based costing. Making the ongoing, dynamic statement of flexibility costs is practically impossible without computer support. Such capabilities are provided, e.g., by simulation modelling which, by performing a series of simulations on variable system configurations, enables the determination of their most advantageous arrangement. The most advantageous system configuration, in a given condition, will therefore become a model, at which the system should strive for (the point of equilibrium between flexibility and leanness. In business practice, a time meter is used to express internal flexibility. It determines the response time to changes in input factors, which are a weighted response time average derived from the change of resources (Tz), processes (To) and production plans (Tp).

3. DYSFUNCTION OF THE INTERNAL FLEXIBILITY IN LEAN MANUFACTURING

Flexibility, especially in excess, causes a dysfunction of the manufacturing system in terms of the essence of creating the manufacturing system based on reducing of all kinds of wastes; therefore, constructed to realize the processes in the most efficient way (without waste). This dysfunction arises from the mutual relationship of the lean manufacturing concept and the flexible manufacturing concept. The fundemtal problem in the balancing process is that both the flexibility and the leanness of manufacturing exclude each other (i.e. what is lean cannot be flexible, and vice versa) [17].Therefore, the most important problem is to be able to balance the level of leanness and flexibility in such a way as to achieve market objectives at the least cost. Such balancing takes place through the process of improving the manufacturing system, which is indispensable for its development. System improvement involves changing protocols, perceptions of behavior and expectations. It can be defined as a planned and top-level effort to increase system efficiency and effectiveness, therefore, continually improving its performance through planned and integrated operations. Even though, improvement can be done in many ways, it can be achieved in such as being formalized or not [18]. Most commonly used formalized improvement approaches for manufacturing are: word class manufacturing (WCM), manufacturing fit approach (xMS), and manufacturing excellence (ME).

4. SELECTED CONCEPTS FOR SYSTEM IMPROVEMENTS AND INTERNAL FLEXIBILITY

As indicated by research, the groups of large manufacturing companies in Poland, today, have currently generated any and all concepts to improve manufacturing. Their efforts are singly aimed to increase the performance level, practically by all companies. Unfortunately there is no comprehensive research related to the use of a preferred concept. However, as shown by studies conducted in a group of 50 large manufacturing companies in the automotive industry in Poland, the most popular are: xMS (82 %), WCM (10 %), ME (1 %), other (7 %). WCM is based on guidelines that can be briefly characterized as: produce faster, produce better, produce cheaper and produce more. Furthermore, literature analysis carried out under the WCM concept has shown that there is no universally recognized and internationally recognized WCM definition [19-21]. However, one can assume that WCM is a way of organizing production systems by achieving the highest, possible level of production oranization implementing modern management methods. Organized according to WCM guidelines, based on so-called technical and management pillars, indicates the highest level of organization possible to achieve. Built on the basis of good practices to reduce all kinds of wastes, the WCM concept is based on lean manufacturing guidelines that reduce the system's internal flexibility to a relatively minimum (what is lean and can not be flexible). The current WCM concept is recognized as a management model, utilized by management in organizations, which have the world's best manufacturing systems, and therefore relies on the basic principles [22] inter alia: respect for established views and standards, no tolerance to losses, removing causes rather than effects. Due to diversity and the rate of change in the business environment, maintaining a uniform standard for any WCM enterprise is increasingly more difficult. In business practice, the addition of the use of proven standards, creates its own set of organizational guidelines. Manufacturing systems that implement the WCM postulates don‘t follow the established standards function as dedicated, well-fitting manufacturing systems (xMS). xMS is agile designed for the individual manufacturing companies that aspire to have WCM-compliant systems but are implemented in other ways. They consist mostly from: foundations, pillars, facades, equipment. They are intended to have greater internal flexibility as they should balance the level of flexibility and leanness of manufacturing. By making the assumption on the capability to balance the leanness and flexibility levels, it is possible to determine the flexibility corridors, and thus to minimize the costs of internal flexibility for the entire system [23]. Problem solving leanness and flexibility to some extent solves agility, where flexibility is a key element for many concepts therefore providing more flexible manufacturing resources and concepts to organize the so-called focused flexibility systems. Excess of flexibility (spare flexibility) is based on the flexibility of corridors or dispersion of resources. Excellence within manufacturing is widely presented as providing significant benefits, but there is no clear consensus regarding the exact nature of excellence within manufacturing, or approaches for its implementation [24]. The ME concept, like xMS, leads to world class manufacturing, although, through other means of implementing methods and tools. It provides an intermediate between the implementation on the basis of WCM and XMS procedure. Manufacturing excellence can be considered as the goal to which every company wanting to be world-class has to move towards. The elements of manufacturing excellence can be made into the pillars on which the roof of manufacturing excellence stands, and the foundation to the nine pillars is provided by top management support in terms of leadership and people support through change and human resource management. Knowledge management has been taken as an inclusive part for all pillars [24]. In ME concept, one of the main pillars is the process flexibility pillar, which is supposed to maintain an adequate level of internal flexibility. It is a concept that generates higher maintenance costs for the system in a state of equilibrium, thus generating more and greater wastes.

5. SIMULATION EXPERIMENTS

As stated, based on literature review, the smallest level of internal flexibility should have WCM-based manufacturing systems, larger xMS and the largest - ME-based manufacturing systems. The purpose of the experiment was to check the levels of internal flexibility of two very similar manufacturing systems, however, developed on the basis of other manufacturing paths (WCM / XMS). Therefore, very similar companies have been chosen producing the same assortment (car lamps) in similar quantities (about 500 pcs/shift), using similar technology (final assembly) and machine park (8 machines), operating in the same system (manufacturing cells) designed for cellular manufacturing and engaging the same human resources (6 operators working on the *1* to *n* system). To verify assumptions, a universal computer model was built based on the analyzed area. For this purpose, the Witness software and an in-built optimization algorithm incorporated in the Witness Optimizer module were employed. The experiment was conducted in 3 stages:

- the possibility of carrying out the same production orders in both areas were verified by assigning them historical WCM quantitative and qualitative plans - 100 consecutive shift plans,
- the possibility of carrying out the same production orders in both areas was verified by assigning them historical quantitative and qualitative plans from the xMS area - 100 consecutive shift plans,
- the possibility of performing the same production orders in both areas was verified by assigning them a virtual quantitative inventory plan, resulting from historical data analysis in the form of possible scenarios (10x10x10). For each of the scenarios, the probability of occurrence was determined by quantifying and

averaging the opinions of experts, specialists from two process management companies in the presented areas. The range of changes and their probability was compiled, based on historical data from a 2 year period (relative stability of the assortment). Weights of the individual variables were determined for each simulation variant identified in the 3 phases (based on historical data averaged over the past 2 years), which are composed of the cost of internal and response time to changes.

Using a modeling simulation can provide an analysis of possible scenarios, which allowed you to choose the most advantageous solution. The choice of the most favorable variant (scenario) is described by the criterion functions: minimum cost [14] and minimum response time. Thus, changes were made in the experiment: planning and control flexibility, process flexibility and resource flexibility by modifying the production orders, products and the amount of resources involved, therefore modifying interdependencies in the dynamic structure of the manufacturing system (unchanging static structure).

6. RESULTS OF SIMULATION EXPERIMENTS

Results from the simulation experiments have been compiled based on the cost and response times for the simulated change. Charts (**Figures 1-4**) illustrate the values of the internal flexibility indices from two production areas - WCM and xMS. These indices are generated by comparing the value of the flexibilities obtained by subsequent simulations to base value, i.e., determined on the basis of actual values. The subsequent values of flexibility were therefore referenced to the same base value (at $t = 0$, the value was 1). In the first stage of the simulation, production basket orders were used in the WCM area while simulating its execution in the xMS area. Results of 100 simulations showing cost of elasticity and response time to changes in the two systems are shown in **Figures 1 and 2**.

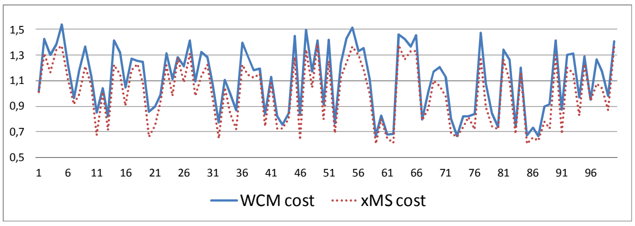

Figure 1 Internal flexibility cost index (WCM-xMS)

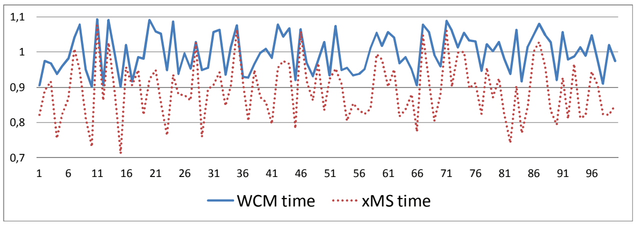

Figure 2 Reaction time indicator (WCM-xMS)

As shown in **Figures 1** and **2**, jobs originally executed in the WCM area and then simulated in xMS, have a 5 % lower execution cost (min - 1 %; max - 10 %). Additionally, it took shorter, on average by 11 % (min - 3 %; max - 19 %). These values are primarily due to excess resources resulting in decreased cost and time of execution for orders and a decreased utilization of system's resources. In the second stage of the simulation, a basket of production orders was implemented in the xMS area and simulated its execution in the WCM area. The results of 100 simulations showing the cost of flexibility and the response time to changes for both systems are shown in **Figures 3 and 4**.

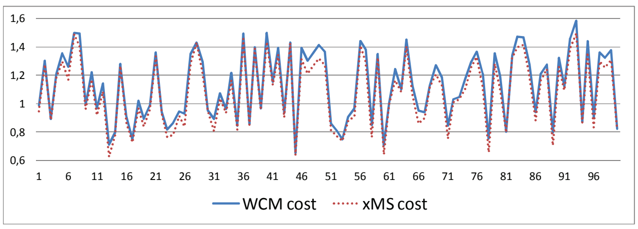

Figure 3 Internal flexibility cost index (xMS-WCM)

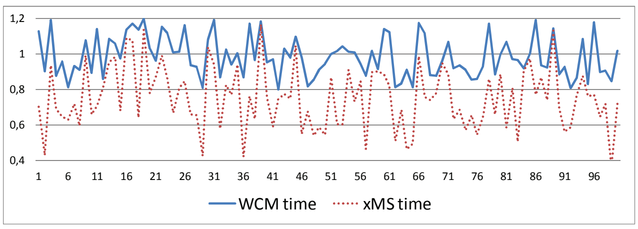

Figure 4 Reaction time indicator (xMS-WCM)

As shown in **Figures 3** and **4**, jobs originally executed in the xMS area and then simulated in WCM, have a 10 % higher execution cost (min - 2 %; max - 20 %). Additionally, it took longer, on average by 24 % (min - 2 %, max - 49 %). These values are primarily due to insufficient resources, which results in increased cost and time of execution of orders. In the third stage of the simulation, virtual production baskets were prepared to create scenarios and then simulated (generating cost and response time minimum values) in the two analyzed areas. The results are shown by means for which the base value was the average of each of the two experiments (**Figure 5**).

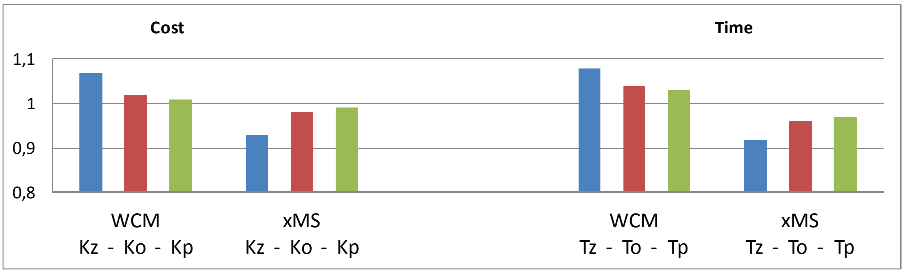

Figure 5 A summary of cost and time indicators for WCM and xMS areas

As shown in the diagram (**Figure** 5), the same order basket produces less cost and shorter lead time from the xMS area. This is mainly due to the excess flexibility of assuming a larger xMS. In the area of cost of internal flexibility this difference is 20 % (resource flexibility (Kz) - 14 %, process flexibility (Ko) - 4 %, plan flexibility (Kp) - 2 %) and in the time domain, 30 % (resource flexibility (Tz) - 18 %, process flexibility (To) - 7 %, plan flexibility (Tp) - 5 %).

7. CONCLUSION

Results from the experiments show that it is possible to generalize the internal flexibility of the manufacturing system. And, as predicted, based on literature analysis, the level of internal flexibility in an xMS-based system is greater than that of a WCM-based system. This is primarily due to the overcapacity of assumptions built into the systems for which the main criterion in their construction is to not minimize all sorts of manufacturing wastes. Solutions based on WCM are rigid solutions, designed to implement a stable order basket. This means that their flexibility in relation to cost increases requires a comprehensive analysis of the level of leanness and flexibility, and thus, its dependence. Excessive internal flexibility in xMS systems with respect to WCM, results in higher maintenance costs, however, allows for a faster execution of tasks. By combining the cost of reducing the execution time with the cost of keeping the excess to current needs, the flexibility of various configuration variants can be tweaked to determine the best level of internal flexibility in a given circumstance.

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