THE LEAGILE MODEL OF THE WORD CLASS MANUFACTURING SYSTEM

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Abstract

Contemporary production enterprises keep seeking organizational capabilities to enable them to function in the network environment. The requirements of Industry 4.0 for production virtualization and digitalization, cloud manufacturing or extended manufacturing impose the requirement to use system integration tools, intelligent robotization and automation or fast reconfiguration, as well as a package of methods and tools that accompany organizational changes. One of the concepts of improving the activity of manufacturing systems, which fits into the course of such organizational changes, is Word Class Manufacturing (WCM). In order to better adjust WCM-based systems to the requirements of Industry 4.0, a model of the lean-agile (leagile) world class manufacturing system was created. In practice, it enables the flexibility - reduced in hitherto existing models - to be adapted to the requirements of Industry 4.0.

Keywords: Wcm, world class manufacturing generations, leagile wcm model

1. THE DEFINITION AND BASIC MODELS OF THE WCM

World Class Manufacturing, besides Manufacturing Excellence (ME) [1] and hybrid solutions xPS (xProduction System) [2,3], is a global approach of an industrial enterprise to striving for excellence. WCM, understood as a comprehensive approach to management, enables the creation of an Integrated Management System in the enterprise based on its own, i.e. developed in-house, model of excellence. The creation of this model relies on problems known in the literature, so-called good practices undertaken by industrial enterprises representing world class manufacturing.

The origin of WCM goes back to the time when good practices were formalized by Japanese enterprises. Striving for manufacturing excellence, carrying out continuous improvement programmes and maximizing the utilization of manufacturing capability in a broad sense, contributed to the formation of a unique form of manufacturing organization, which allowed the world class status to be attained. A literature review carried out in the area of WCM has shown that there is no universal, recognizable and worldwide accepted definition of WCM [4,5]. World class manufacturing relies on guidelines that can, in brief, be expressed as: manufacture faster, manufacture better, manufacture cheaper and manufacture more. Fulfilling these guidelines requires the highest level of organization, low-cost structural flexibility and the associated response speed and adaptability to the changing market and technological environment. Based on the semantic analysis of the term WCM [6] it can be accepted that world class manufacturing is a method of improving system organization, which enables the highest possible level of manufacturing organization to be achieved by implementing modern management methods. Organization, according to the WCM guidelines, currently means the highest achievable manufacturing organization level and is largely based on the following principle: “manufacture the best products at half the cost, with half the effort and in half the time” [7]. So, the current notion of WCM differs substantially from the concept of good practices integration, which results from the natural evolution of continuous improvement. The contemporary understanding of WCM most often means a manufacturing strategy that is pursued using a set of (operation) management methods. As shown by the analysis of the course of WCM implementations, WCM is most commonly perceived only as a set of operation management methods that contribute to an improvement in the productivity of enterprises and enable them to build a strong

competitive position in the marketplace. Within the contemporary interpretation of WCM, therefore, many management methods can be indicated, which form the so-called package of WCM operation methods [8].

During the course of the evolution of the WCM concept, numerous defined models have come into being. All models have generally been created by the modification of R. Schonberger's base WCM model comprising the set of the best practices. Considering the fact that there has been no consistent WCM model developed so far, the majority of models have been set up by grouping good practices into sets of methods and concepts that have some common effects of influence on enterprises ascribed to them. The most widely known WCM models include [6]: Schonberger's model (1986), Hall's model (1987), Gunn's model (1987), Maskell's model (1991), Sharma and Kodali's model (2008), Nachiappan's et. all model (2009), Gandhi's et. all model (2011), Okhovat's et. all model (2012), the agile model (2013), the WCSM model (2015) - the listing has omitted the EQFM [9], UKBI, EVA [7], WCM–MTO [10], WCML [11] - for more see [6].

2. OPERATIONAL FLEXIBILITY IN WCM MODELS

One of the main factors influencing the capacity for transformation toward the Industry Requirements 4.0 is operational flexibility being smoothly adjusted to current needs. Operational flexibility is understood as the ability to respond to foreseen or unforeseen (internal or external) changes, which boils down to the intentional and economical maintenance of the reserves of specific resources to be used in the appropriate time [6]. The analysis of changes in WCM models has shown that along with their development, the approach to operational flexibility also changed. The analysis of the existing models shows also that in the initial periods of implementing WCMs, striving for low manufacturing costs and orientation to quality did not cause any significant increase in competitiveness [12], hence the interest in increasing the diversity of products offered (an increase in flexibility) [13]. This was reflected in subsequent WCM models, which to an increasingly large extent considered the flexibility (of product and volume) at the cost of the drop in cost effectiveness. An apogee of including flexibility in WCM models occurred in Maskell's model, in which the main component became flexible production. A confirmation of the trends in increasing importance of flexibility were the works by various authors, including R. Markland et al [12], in which, from among the thirteen priorities of competitiveness, three concerning the flexibility (of product, volume and process) took the highest places in the ranking. With the inclusion of lean manufacturing postulates in WCM, a decrease in the level of operational flexibility occurred. This resulted from the change in priorities oriented primarily to the elimination of any types of losses, aimed at reducing the unit production cost to a relative minimum, and then to the delivery of an added value to customers. So, a significant decrease in operational flexibility took place due to the reduction of losses, in which the redundant flexibility of resources with respect to current needs made up the largest value of the costs of generated losses (in particular, losses associated with maintaining redundant resources). This redundancy resulted from the tendency to making a quick reaction to variable needs of customers and the environment's variability (unpredictability) itself. The reduction of the costs of redundant flexibility especially in the area of resources, and thus the decrease of its level, is part of WCM "philosophy" (zero losses), hence subsequent WCM models reduced operational flexibility to a minimum value. A breakthrough in including flexibility (in particular operational flexibility) were third-generation models, where flexibility, on the assumption of being included in the agile manufacturing concept, became an essential element of WCM. Those models started to effectively utilize the flexibility by the ability to "dose" it through the appropriate cost calculation of the level of its involvement (so-called low-cost flexibility) [14]. As analyses show, the total level of flexibility (strategic flexibility) has been constantly increasing in recent years, with periodical fluctuations of operational flexibility. This corresponds with the analysis of the level of operational flexibility in the area of WCM (**Figure 1**).

As shown by **Figure 1**, in the initial phases of development of WCM models, flexibility was in-built in good practices and was continuously increasing (first-generation WCM models). The introduction of second-generation models resulted in a lowering of the level of flexibility, but only the one associated with the operational level and carrying out of processes based on the enterprise's own resources. Its shortage in the

system was compensated for by the ability to subcontract all or individual fragments of manufacturing processes. Hence, the most common in that time forms of manufacturing activity as the areas of the final manufacturing phase (most often, final assembling). Third-generation models, in turn, which assume the unpredictability and variability of environmental conditions, reserve resources and thus maintain flexibility redundancies. This is most often done in the form of negotiating the allocations of dispersed resources. Carrying out activities in such systems, despite no physical utilization of resources at the network building stage, generates costs related to the reservation of potential resources, thus contributing to maintaining redundant flexibility. This phenomenon seems illogical, if only because of the calculation of variability costs, and manifests itself in incurring the costs of reducing the level of operational flexibility, followed by incurring costs due to increasing its level again. In this case it is useful to assess the minimum level of operational flexibility reduction (estimation of flexibility fit), below which incurring the costs of its further reduction will involve another costs due to restoring it to the necessary level. This paradox stems from the assumptions of theoretical models used for the creation of manufacturing systems (especially those based on second-generation models), for which lean manufacturing that reduces losses to a minimum is a fundamental base construction. Presently, world class manufacturing systems should be integrated systems that improve their processes and product quality, reduce costs, but also enhance flexibility, while meeting diverse customer expectations [15] (so-called agile systems). A model that fits into the trend in gradual increasing the level of operational flexibility from lean systems toward agility is the developed leagile system model.

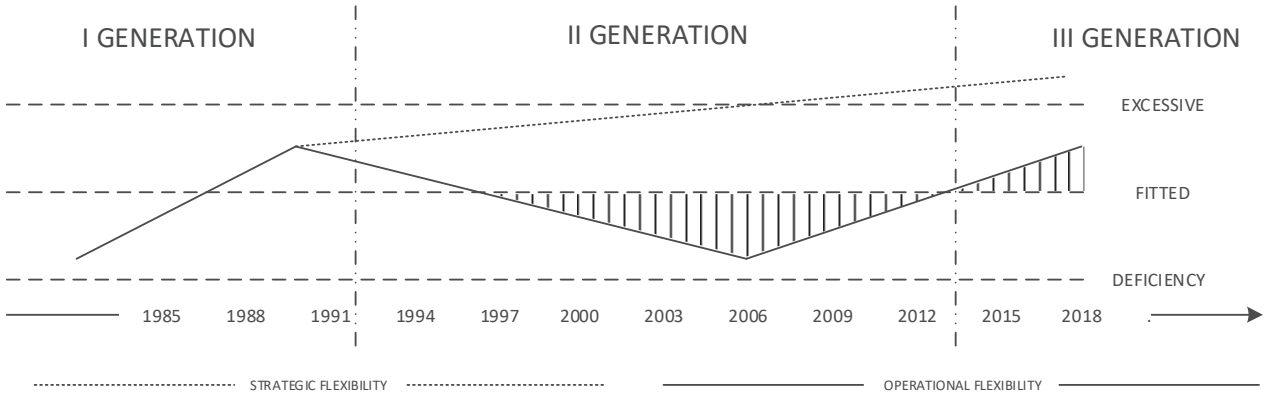

Figure 1 The level of operational flexibility in WCM models

3. THE CONCEPT OF WCM LEAGILE MODEL - TOWARDS INCREASING FLEXIBILITY

The proposed model is a combination of the best practices concentrated around six base concepts, namely:

- TPM (*Total Productive Maintenance*), which ensures the effective use of resources,
- L6S (*Lean Six Sigma*), which ensures the minimization of activity costs, while maximizing the added value and assuring the quality accepted by the customer,
- FM (*Flexible Manufacturing*), which provides the proactive and fast responding flexibility of processes through the possibility of making quick reconfiguration of resources,
- AM (*Agile Manufacturing*), which provides the ability to make prompt response through the virtualization, customization and networkability of manufacturing at the level of so-called basic agility,
- TFM (*Total Flow Management*), which ensures the most favourable flows of material streams in supply chains,
- TSM (*Total Service Management*), which ensures the most favourable organization of manufacturing-related processes, in particular information flow streams.

The generalized leagile world class manufacturing model is shown in **Figure 2**.

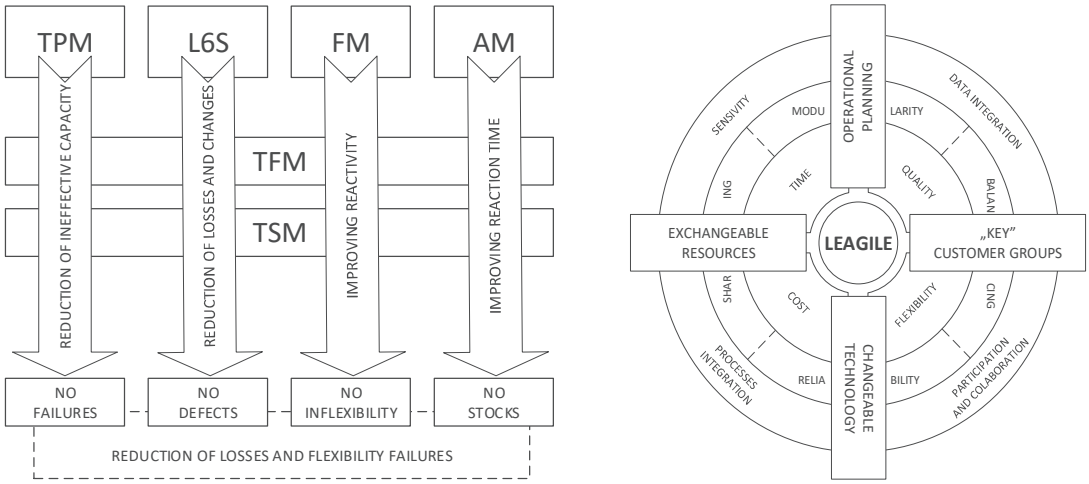

Figure 2 The leagile world class system model

What distinguishes leagile WCM systems is associated with the possibility of considering changes in the area of enhancing operational flexibility and generated losses due to the costs of maintaining redundancies. The process of evolutionary adjustment of existing solutions to increased operational flexibility requires the activities associated with the analysis of the operational flexibility level to be added to the cost analysis pillar and creating mechanisms for balancing the leanness and operational flexibility within it. Based on the performed analyses of research objects (17 facilities located on the territory of Poland and implementing various second-generation WCM models), basic activities aimed at the practical use of the proposed model have been defined. These include, in particular: to maintain the current number and scope of activities in sub-areas (technical pillars), except for the cost analysis sub-area; to add activities related to the analysis of operational flexibility to the cost analysis sub-area by defining the modified pillar as “flexibility cost analysis”; to maintain the current number and scope of actions in the activity fields (managerial pillars); to maintain the stagewise mode of carrying out actions within individual pillars following this sequence: response actions, preventive actions, proactive actions; and to maintain the number of stages in implementing individual pillars. This means that, for leagile world class manufacturing systems, the constructional frameworks of existing models can be used, but, at the same time, making changes in the system of the technical pillars from vertical to matrix one (3T+7T) and complementing the cost analysis pillar with operational flexibility analysis (**Figure 3**).

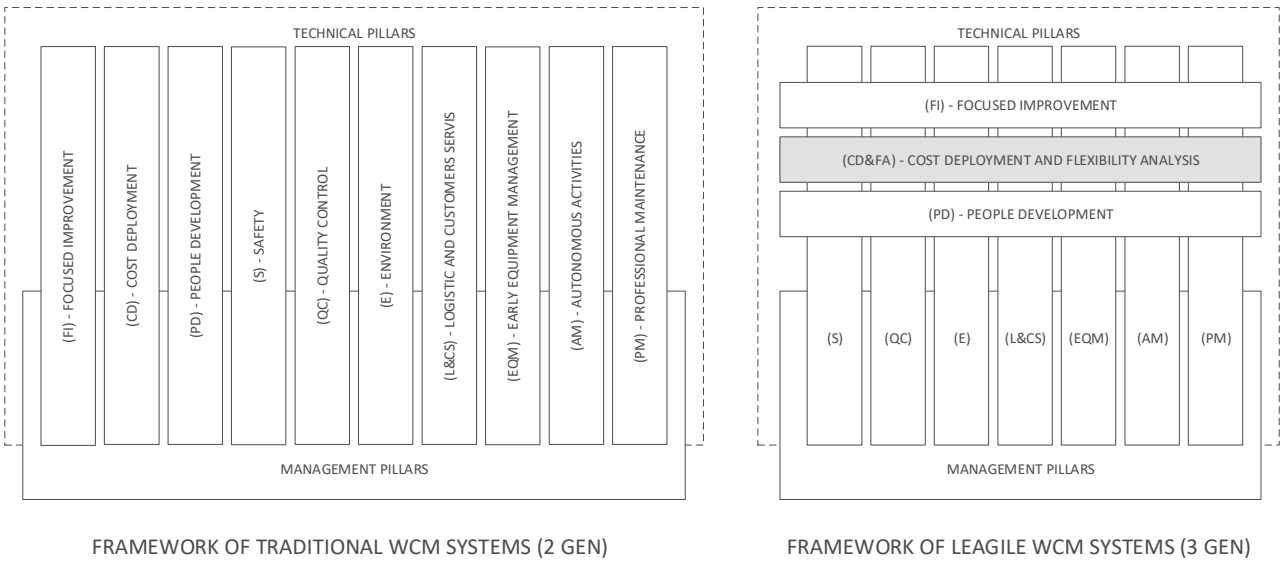

Figure 3 The framework of traditional and leagile world class systems

The most significant change, besides the change of the pillar system, is the modification of the cost analysis area. The new „cost deployment and flexibility analysis“ (CD&FA) is a pillar in which the basic valuation of losses is done, which means the conversion of losses to cost units (flexibility redundancy is a cost assigned to the loss category, so it is classified as a cost-generating factor). Actions taken within this pillar aim, most often, to: indicate main losses in the production-logistic chain; make the value assessment of losses; indicate economic advantages brought by elimination of losses; and indicate resources needed for their elimination. The use of CD&FA takes place while retaining this logical sequence of events: loss - loss source - loss assessment - the effect of loss reduction on flexibility - determining the loss level and the loss reduction method - analysis of the B/C (*Benefit/Cost*) balance - action plan - settlement using so-called cost analysis matrices (matrices A–G) modified by the flexibility factor. When taking actions to eliminate losses that affect the flexibility level, the analysis should be complemented with actions related to balancing the levels of loss reduction and flexibility increase. On the basis of the analyses, a sequence of actions to implement the CD&FA pillar has been proposed (**Figure 4**).

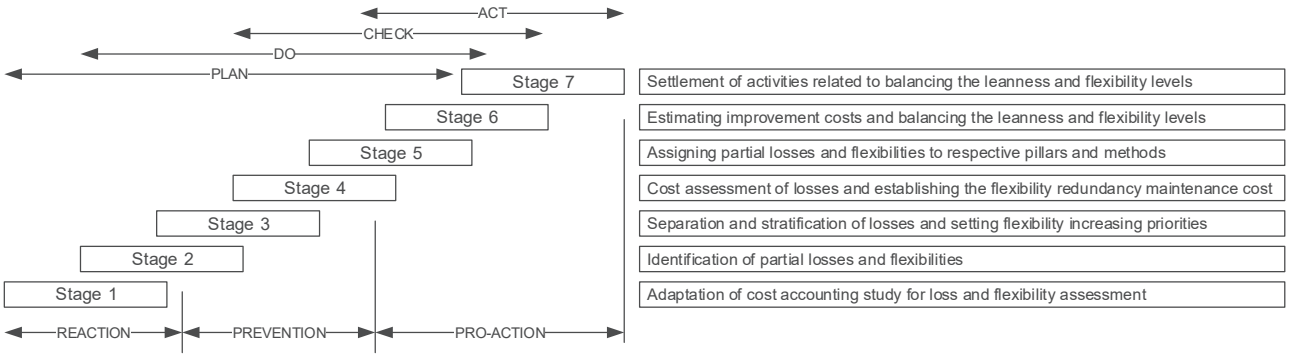

Figure 4 Stages of implementing the CD&FA sub-area (pillar)

4. CONCLUSION

The model presented herein fills the gap between the described models based on lean manufacturing (second-generation) and the agile model. The proposed model is based on the assumption that operational flexibility, as a factor essential for transforming a system towards Industry 4.0, should be smoothly formed, depending on the current needs. This is possible by introducing the sub-area of the ongoing analysis of the level of flexibility and the costs of its maintenance to the constructional framework of classic WCM models. Continuous monitoring of the costs of generated losses and juxtaposing them with the costs of maintaining flexibility redundancies enables the fulfilment of the agile manufacturing assumptions, contributing thereby to an effective and quick action.

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