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Evaluation of flexibility for the effective change management of manufacturing organizations

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ABSTRACT

In this paper, we propose selected flexibility measures which can quantify flexibility and eventually integrate it into the change management processes of manufacturing organizations, aiming to increase effectiveness and competitiveness of the European industry. These measures can be utilized either stand-alone or integrated into a change management system to influence the change direction. A classification model supporting flexibility-related aspects is also discussed. A case study presenting a recommended integration of flexibility into a change management process is described. Additionally, a service-oriented architecture on IT level that can be adopted in order to combine the flexibility calculation with the change management is presented. The final objective is to investigate the integration of quantified flexibility indicators into the change management processes of a manufacturing organization.

1. Introduction

For many decades, cost and production rates were the most important performance criteria in manufacturing, and manufacturers relied on dedicated mass production systems in order to achieve economies of scale [1]. Delivery reliability has also been a primary concern of many companies [2] along with their aim to sustain a satisfactory product quality [3,4]. Nowadays, manufacturing organizations understand that these criteria have been further diversified. The competition has increased and the customer base is more mature. Cost and production rates are not considered adequate criteria anymore. The concept of customer satisfaction has been an underlying part of marketing and it is widely recognised as a predictor of behavioural variables, such as customer loyalty, repurchase intentions and others [5–8]; thus, becoming a primary objective of modern manufacturing firms. Customers today not only do they demand high quality and functionality of a product but also more and more individual product features, short delivery times and the use of the latest technologies [9].

Chryssolouris comments: "As living standards improve, it is increasingly evident that the era of mass production is being replaced by the era of market niches. The key to creating products that can meet the demands of a diversified customer base, is a short development cycle yielding low cost, high-quality goods in sufficient quantities to meet demand. This makes flexibility an increasingly important attribute to manufacturing" [1]. The ability to adapt to dynamic market demands and to ever shortening product life cycles is now a norm for many industries [10].

The turbulent market environments dictate frequent reconfigurations to adapt to emerging demands. To efficiently adapt, the manufacturing systems, in question, have to be flexible. Flexibility has to be considered in the "change decisions" of the stakeholders. However, to consider flexibility, companies must have a way of evaluating flexibility quantitatively [1]. Towards this objective, different approaches have been studied. A method, integrating the Real Options Analysis into Net Present Value calculations for measuring flexibility, in investment decisions, is described in [11]. Approaches to a flexible design for manufacturing systems have been studied [12], while the economic terms for cost effectiveness have also been considered [13]. Furthermore, flexibility in supply chains has been studied [14].

In change management, quantitative flexibility indicators can be exploited to provide the directions towards which the change should take place, when investigating the upgrade of a machine, the investment decision to increase flexibility or the reconfiguration to adapt to emerging production requirements. Additionally, these decisions can be reinforced by the utilization of simulation models in the design or operation phases. Different planning solutions can be tested and compared during simulation, whilst different scenarios (e.g. order forecasts or technical planning solutions) can be simulated [15].

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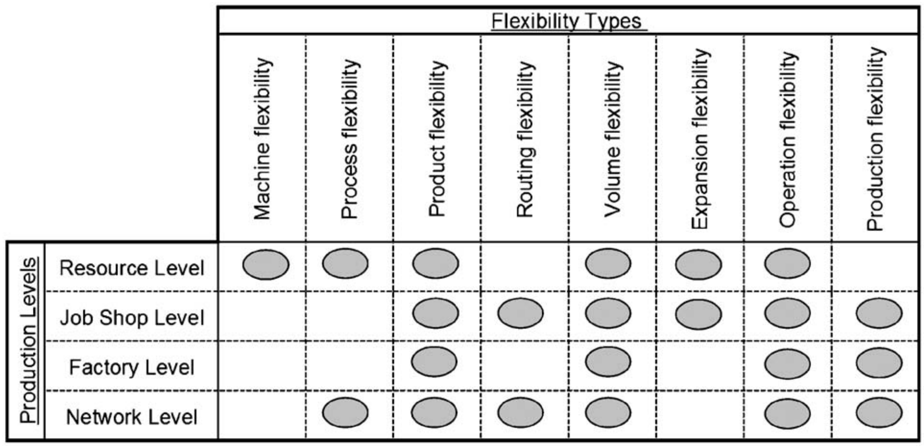

Fig. 1. Correlation of production levels with flexibility types.

2. Flexibility classification of manufacturing systems

2.1. Flexibility types and production levels

High flexibility or low sensitivity to a change provides a manufacturing system with three principal advantages. It is convenient to think of these advantages as arising from the various types of flexibility that can be summarized in three main categories as in Chryssolouris [1]:

- Product flexibility enables a manufacturing system to make a variety of part types using the same equipment. Over the short term, this means that the system has the capability of economically using small lot sizes to adapt to the changing demands for various products (this is often referred to as production-mix flexibility). Over the long term, this means that the system's equipment can be used across multiple product life cycles, increasing investment efficiency.
- Capacity flexibility allows a manufacturing system to vary the production volumes of different products to accommodate changes in the volume demand, while remaining profitable. It reflects the ability of the manufacturing system to contract or expand easily. It has been traditionally seen as being critical for make-to-order systems, but is also very important in mass production, especially for high-value products such as automobiles.
- Operation flexibility refers to the ability to produce a set of products using different machines, materials, operations and sequences of operations. It results from the flexibility of individual processes and machines, that of product designs, as well as the flexibility of the structure of the manufacturing system itself. It provides breakdown tolerance—the ability to maintain a sufficient production level even when machines break down or humans are absent.

Furthermore, to classify manufacturing systems, based on their flexibility-related aspects, an appropriate classification model needs to be identified. The aim is not only to study flexibility at a machine level but also at other levels of the enterprise. Thus, to examine the possibility of an indirect aggregation of flexibility indicators, starting from a machine level and ranging up to a production network, a classification model has to be utilized, to view the manufacturing organization in a hierarchy mode.

An example is the five-layer hierarchical model of production control, the AMRF hierarchy, dealt with in [16,17]. It presents and discusses the following five levels: (i) facility, (ii) shop, (iii) cell, (iv) workstation and (v) equipment. An analysis of traditional small batch manufacturing systems has provided the construction of this hierarchy. In another work, the concept of a task within a control architecture, called intelligent systems architecture for manufacturing (ISAM), is discussed [18].

In another approach, the following coherent classification model is provided in [1]:

- factory level
- job shop level
- work center level
- resource level

The highest level in hierarchy, the factory, corresponds to the system as a whole. A factory can be divided into job shops, which are sets of work centers commonly producing a family of products. A work center consists of resources capable of performing similar manufacturing processes. For example, a turning work center may include some or all of the lathes of a job shop. It should be noted at this point that there is no need for all individual resources to be at the same location in the factory, since a work center is only a logical grouping of resources. A resource is an individual production unit such as a machine, a human worker or a manufacturing cell (a group of machines and auxiliary devices (e.g. robots) that work together to perform an operation). Not only similarities but also differences can be found when it is compared with the five-layer hierarchical model discussed before. We initially identify that the equipment level is not present here, mainly because the latter model is focusing on the manufacturing processes and the resource level encapsulates the equipment pieces. It can be perceived that the resource level here can also be a manufacturing cell employed to perform an operation. The AMRF hierarchy eyes a wider approach, also considering information management, data sources, administrative management (such as accounting and procurement), system interfaces and more. It can also be identified that both of the hierarchy models adequately facilitate the efficient scheduling of manufacturing tasks and the assignment of tasks to production elements.

However, when it comes to flexibility, the need for the supply and manufacturing chain perspective of the enterprise to be addressed, can also be identified. Therefore, another level should be added, that of the network. This level addresses the production network of the enterprise and the outside partners of the enterprise, namely suppliers and subcontractors. Additionally, since the flexibility aspects of resource and work center (group of similar resources) could similarly be perceived, we arrive at the following classification model of four hierarchy levels:

- Level 1: network level (network)
- Level 2: factory level (factory)
- Level 3: job shop level (production line)
- Level 4: resource level (workplace machine)

According to this model, the various production levels of the enterprise can be classified based on the flexibility type that is more significant at each level (Fig. 1). This provides engineers with a quick overview of which flexibility types should be monitored and eventually enhanced at each production level of their enterprise. Fig. 1 provides an example of this correlation utilizing different flexibility types and the classification model proposed previously. It can also be noted that as it can be seen from this picture, the three flexibility types which are on the main focus (product, capacity and operation flexibility as discussed previously), appear in all four production levels. The classification scheme presented in Fig. 1 may of course differ, since modifications are frequently required to adapt to the classification scheme, according to the particularities of the manufacturing organization under study; however, the proposed approach can be used as a basis for the process.

2.2. Flexibility ranking of manufacturing elements

In the second paradigm, another classification scheme is proposed. It is presumed here that manufacturing resources and external partners have been evaluated on the basis of their flexibility and their quantitative results are available. The utilization of the flexibility evaluation toolbox (FET) – discussed next in Section 3 – may provide the required quantitative flexibility evaluation for each element. After this requirement has been satisfied, the various manufacturing elements in this case are classified according to their flexibility ratings and the previously defined classification model (Fig. 2). This materializes a quantifiable taxonomy, which requires that the flexibility of the production systems within the enterprise is assessed quantitatively. It can also be extended to a network level, where the supply chain flexibility may be investigated by the flexibility of the external partners, suppliers and subcontractors. The following figure provides the general concept of these arguments. In this figure, each resource, job shop, factory, supplier and subcontractor has been positioned according to its evaluated flexibility.

The engineer can have a thorough overview of the flexibility that is demonstrated by the various internal and external elements of the manufacturing enterprise. This enables the selection of the most flexible resources and/or external partners when high levels of flexibility, such as in cases of unexpected high demand, urgent orders and more, are required. Additionally, by examining this classification, the engineer can assess how the various elements of the production enterprise can respond to emerging demands and properly decide as to which elements need to be upgraded. This can also apply to the network level where, by selecting the more flexible suppliers and subcontractors, the engineer is able to indirectly enhance the flexibility of the company.

3. Flexibility evaluation

However, to consider flexibility, companies must have a way of evaluating flexibility quantitatively [1]. This will enable the integration of flexibility to decision-making procedures and taxonomies as proposed in the previous chapter. For this to be achieved, the flexibility evaluation toolbox developed in [19] can be utilized.

Five individual flexibility measures compose the flexibility evaluation toolbox: the penalty of change (POC) [20–22], the ζ-analogy method [21,23], the design of systems for manufacture (DESYMA) [24,25], the FLEXIMAC [26] and the reaction-time analogy [27]. Short descriptions for each of the five flexibility measures are provided in [19] and are repeated hereafter.

- Penalty of change is a generic measure since it can be applied to different flexibility types and combines both technological and economical terms.
- DESYMA is based on measuring flexibility with the help of demand probabilities.
- The 'ζ-analogy' method makes use of an analogy between a manufacturing and a mechanical system.
- FLEXIMAC can be valuable for comparing different production systems when they have been exposed to a similar excitation of the external environment.

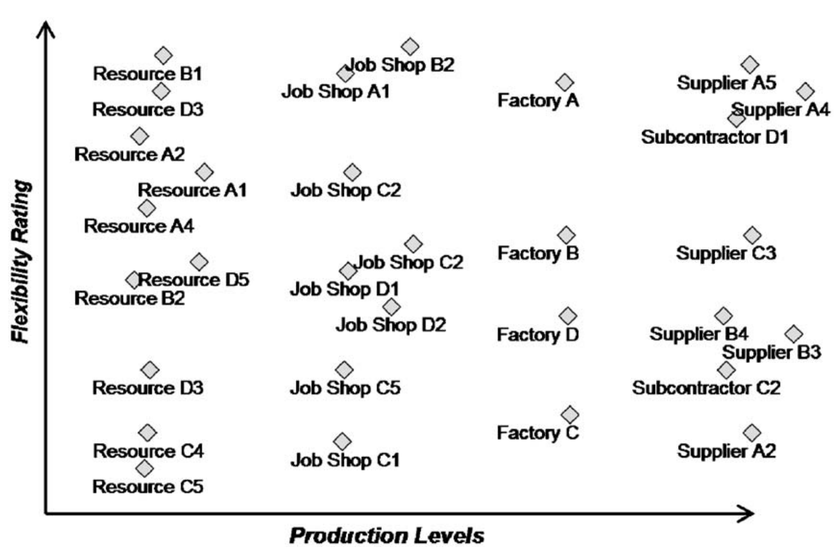

Fig. 2. Example of classification based on quantitative flexibility evaluation.

- The 'reaction-time' analogy method is an approach to modelling and analysis of the dynamic behaviour of manufacturing systems.

The flexibility evaluation toolbox provides the means of addressing a wide range of cases at different enterprise levels. Additionally, another advantage of the flexibility evaluation toolbox is that the hosted measures can be appropriately selected to readily exploit simple data available from the installed IT systems of the company. The main attainment is that depending upon the case under study, the responsible stakeholder is able to select the most appropriate measure from the flexibility evaluation toolbox to quantitatively measure flexibility.

4. Flexibility and reconfiguration of production lines

In this section, the integration of flexibility evaluation (FE) in a change management procedure is investigated. Production firms usually divide their workshop floor into a number of separated production lines that are specifically assigned to the production of one model or a specific model range. According to the specific objectives of the company, often in terms of production-to-demand ratio, each model is allocated to a specific production line. However, manufacturing enterprises, in strong competitive environments, frequently have to consider the reconfiguration of their production lines to adapt to emerging demands.

In this case, the reconfiguration of the production lines in a factory is examined from the time point of the initial change triggers until the final implementation. This process has been divided into four basic phases: the change definition phase, the detail planning phase, the decision-making phase and the final-implementation phase. As expected, during these basic phases, secondary activities take place as shown in Fig. 3.

In Fig. 3, it is indicated where flexibility evaluation should take place in order to support the reconfiguration and direct it towards better results. Both flexibility evaluation and system lifecycle change management activities are addressed. Flexibility evaluation takes place for the final decision of the new factory layout plan to be supported. According to the produced flexibility indicators, a reconsideration of the final plan may take place. Additionally, during the final assessment of the implemented reconfiguration, the flexibility evaluation can inform the engineer

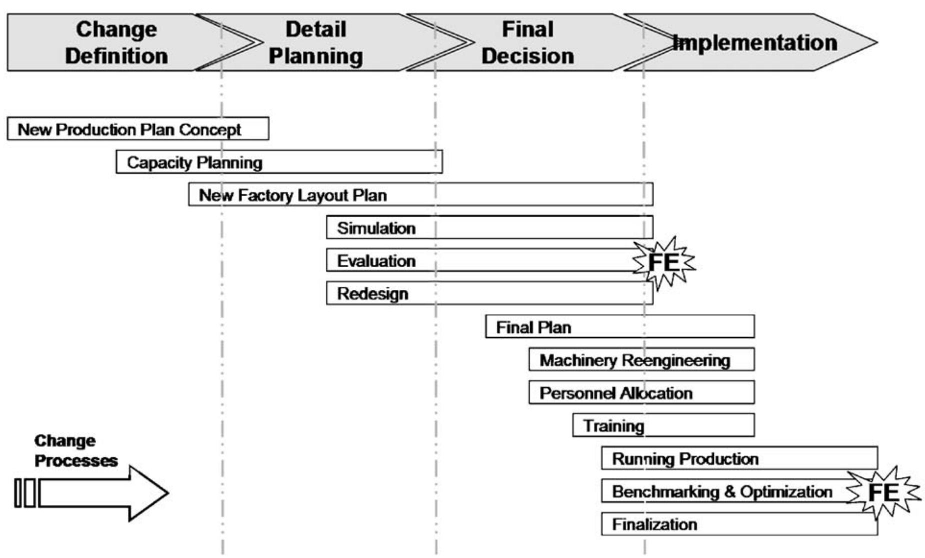

Fig. 3. Reconfiguration phases.

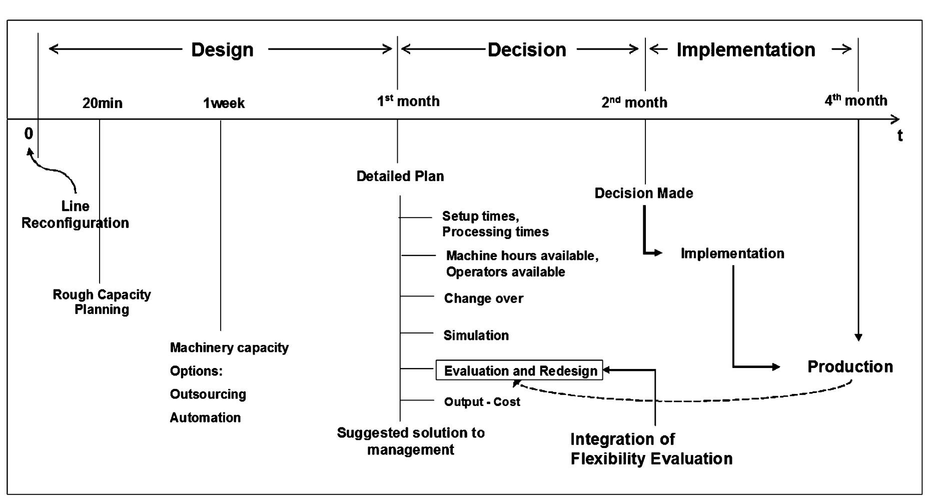

Fig. 4. Reconfiguration of production lines.

about the flexibility of the new production layout being available and indicate any existing bottlenecks.

Fig. 4 provides more details for each phase concerning the specific case that has been studied. The related timeframe and the exploitation of flexibility evaluation are also indicated. The flexibility evaluation supports the decisions of the stakeholders being responsible by indicating the most flexible solution that may be applied. In other cases, flexibility evaluation may also support investment decisions. Practical approaches and examples of flexibility evaluation have been provided among others in [20–22,24].

5. IT infrastructure for the integration of flexibility and change management

In this section, we shortly describe a software platform that can be utilized for flexibility evaluation and change management to be integrated. The platform architecture is provided in Fig. 5.

The main components of the proposed platform are the flexibility evaluation toolbox, the change management component (CMC) and the application controller [28]. The flexibility evaluation toolbox was previously discussed in this paper. Short descriptions of other components are provided hereafter.

The change management component handles the functionalities related to the change management processes such as:

- the modelling functionality for the cross-organisational process modelling;
- the mapping of company internal processes into cross-organisational process flows.

The application controller is responsible for the following tasks:

- integration of results from the monitoring and measurement of the system flexibility into the change processes;
- orchestration of all necessary services;
- user management and security issues.

Furthermore, the external systems that may be served include

- ERP, PPC and other applications that can deliver data required for the flexibility measurement;
- BPM or PDM systems, which focus on the process view, deliver the required input data for the change management component.

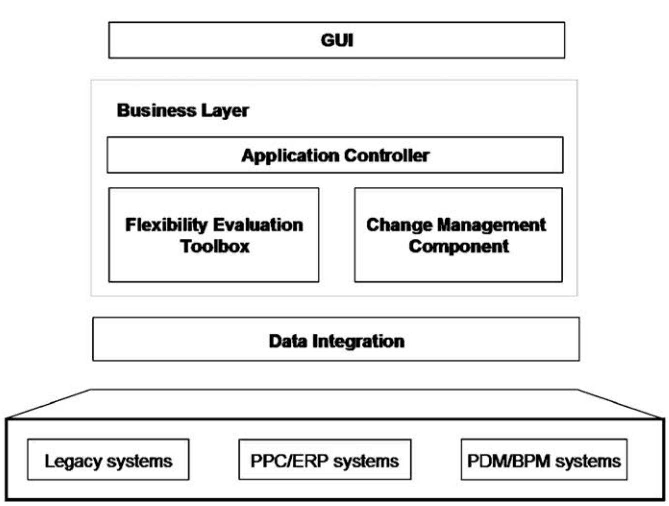

Fig. 5. Platform architecture [29].

6. Conclusions

This work aims to introduce the benefits of integrating flexibility considerations into the change management of manufacturing systems. The quantification of flexibility enables this integration. It can be used for supporting the engineers in their decisions, to help them evaluate their decisions and final plans as well as to evaluate the responsiveness of manufacturing systems to any disturbances. Integrated use of this information is expected to improve the responsiveness of the factory at all levels, since it will provide an overview on the performance of the various departments when the needs for changes arise.

Further to this work, the exploitation of flexibility evaluation as an identifier of bottlenecks and as a trigger for change actions has to be explored. This aims to provide engineers with a picture as to which activity or station needs improvement to proactively increase the factory's responsiveness to unexpected events.

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