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Abstract. With an aggressive economic competition on a global scale, more educated and demanding customers, and a rapid pace of change in process technology, responsiveness in manufacturing is becoming a key competitive advantage. The present paper examines how responsiveness can be achieved in SMEs operating according to an Assemble to Order strategy. The framework – proposed starting from literature analysis and tested through a first case study – will be used in future works to drive a systematic analysis of responsiveness in SMEs.

Keywords: Responsiveness, Flexibility, Agility, Assemble To Order

1 Introduction

Manufacturing companies, nowadays, are facing fierce pressure to cope with rapidly changing market demands for high variety, more customized products and quick delivery [1,2]. Manufacturing is in fact evolving from mass production to mass customization and personalization paradigms [3]. However, these new paradigms face many new challenges, such as high cost and increased lead times, due to the complexity induced by high variety [4,5]. This complexity increases on the shop floor because of additional product changeovers, more routing alternatives, larger volumes of work in process, assembly line balancing problems with mixed models, increasing process variability, etc. [5]. Nevertheless, to stay competitive, companies require delivering customized products rapidly and cost-effectively [6], and this responsiveness is considered as a key challenge for future manufacturing.

Interestingly, a recent survey ([7]) found that Small and Medium-sized Enterprises (SMEs) in Italy are more responsive than large enterprises, claiming that they are capable to deliver faster because they manufacture and assemble items very quickly. Notwithstanding the findings, there is still little empirical evidence to clarify how SMEs are actually adapting to provide quick response to a changing demand. Then, the aim of our research is to explore different approaches that SMEs adopt to enhance their responsiveness. This study is part of the research and particularly focuses on the assembly process with the purpose to investigate different characteristics that lead to higher responsiveness in SMEs operating according to an Assemble To Order (ATO) strategy. Two research questions are driving the work: i) what are the different approaches that SMEs adopt to enhance responsiveness of their production systems? ii) how can manufacturing responsiveness be achieved in the context of SMEs operating an ATO strategy with manual assembly? As it is an initial work within the frame of our research plan, the paper will provide preliminary findings in this regard. Owning the exploratory nature of this phase of the research, the case study approach was considered to be an appropriate methodology [8] to identify and analyze key approaches adopted and how they help to achieve higher responsiveness. In this regard, the unit of analysis selected for the case study is one of the manufacturing plants of a selected SME in Italy because of its high responsiveness: the plant has been investigated using unstructured interviews and by on site visit to observe its actual functioning.

Section 2 provides the results of literature analysis, section 3 presents the conceptual framework; the case study is eventually discussed in section 4.

2 Literature Analysis

2.1 Manufacturing Responsiveness

The original debate about manufacturing responsiveness was focused on the concept of "*time-based competition*" [9,10]. Soon the debate enlarged the scope, considering competitiveness based on the capabilities to react to all kinds of changes rapidly and cost-effectively [6]. In particular, changing demand and market needs have been emerging as relevant issues, as remarked by [11] in his definition of responsiveness: "*the ability to react purposefully and within an appropriate time-scale to customer demand or changes in the marketplace, to bring about or maintain competitive advantage*". Therefore, the changing demand regards also the modifications in the product portfolio, as pointed out in [12] where responsiveness refers to the speed at which a plant can meet changing business goals and produce new product models. Overall, the above mentioned (and other similar) definitions focus their attention on the competitive priorities and resulting benefits that the manufacturing system should address to achieve a winning position in the market through responsiveness. Conversely, the conditions that enable the system to be responsive are not particularly taken into account: a further insight from an operations management perspective is required.

In this regard, it is worth citing again [11] that identified three dimensions of responsiveness: product, volume and process. The dimensions concern respectively the ability to renew the product range through the rapid introduction of new models, to modify the production volumes, and to quickly manufacture and deliver items. Responsiveness of a production system is influenced by different variables such as position of customer order decoupling point [11], set-up times [7], production resources and system design (equipment and workers) etc. [6], [12].

2.2 Flexibility and Agility as Lever for Responsiveness

Flexibility has been at the focus of academic discussion for a long time. It is considered as "an operating characteristic" being defined as "the ability of a system to change status within an existing configuration (of established parameters)" [13]. As originally conceived, flexibility is characterized by three types of operational flexibility, relating to technology, labor and infrastructure [14] as the levers to support changes of an existing configuration. Different concepts implementing flexibility are then proposed: as a meaningful example, it is worth mentioning the concept of Flexible Manufacturing System (FMS) [15], one of the most popular in the history of flexibility in manufacturing. Although the FMS was claimed as a response to the increasing need to produce variety of parts, some limitations such as high complexity [16] and low system output [17] constrain its capability to cope with challenges of high fluctuation in the product demand and mix, as new market conditions demand a higher degree of flexibility than traditional FMS. Moreover, with high cost of general flexibility [18] and low output, a relatively high cost per part is expected with FMS. Also flexibility through FMS is obtained by assuming a constant amount of information and absence of learning process [19], while over time manufacturing plants should be able to make different decisions – for their structural and infrastructural resources –, learning from past experience and adapting to changing needs. Therefore, to be more responsive, manufacturing firms have been looking for approaches towards other forms of flexibility, capability to cope with dynamics, hence particularly looking at the effective use of changeable and reconfigurable structural and infrastructural resources within a plant. Agile manufacturing has emerged to this end. Agile manufacturing, or agility, is defined as "*an ability of the system to rapidly reconfigure (with a new parameter set)*" [13]. The concept of Reconfigurable Manufacturing System (RMS) has been proposed to achieve agility in manufacturing systems. RMS is intended as "*a system designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or regulatory requirements*" [6]: this definition provides the major emphasis on the design of manufacturing systems with adjustable resources, in order to enhance the responsiveness to changes. More specifically, [17] asserts that six core characteristics of RMS: customization (leading to adjustments to guarantee the production of parts within given product families), convertibility (enabling to easily transform the functionality of existing systems and machines in order to suit new production requirements) and scalability (supporting to easily modify the production capacity by adding/subtracting manufacturing resources and/or changing components of the system) can be considered as the key characteristics to enable reconfiguration; modularity (leading to the manipulation and optimal arrangement of modular units between alternate production schemes), integrability (with the purpose to integrate modules rapidly by a set of mechanical, informational, and control interfaces) and diagnosability (representing the ability to diagnose the problems, and quickly correct operational defects) contribute to the rapid reconfiguration. A manufacturing system having these characteristics is considered as highly responsive.

2.3 Achieving Responsiveness through an Assemble To Order Strategy

ATO is a production strategy for customer order fulfillment, proposed as a form postponement [20] and implemented in assembly systems to produce unique variants within a product family [21]. As an order-driven production strategy, ATO production system faces swings in demand, thus high variability in the capacity utilization of the assembly systems; moreover long order lead times can be expected as only the component parts/sub-assemblies are hold in stock while finished products are not [22]. Therefore, to remain competitive, the production system must be properly designed with the objective to be responsive to the customer issues and, at the same time, achieve production quality and productivity.

To this end, different strategies have been proposed especially with the purpose to mitigate complexity. According to [23], to effectively manage the variety, in-house reengineering should be initiated when an ATO strategy is decided, with the purpose to flatten bills of material, simplify designs and standardize components and to obtain commonality in as many of the base components as possible within a product family. Component family and commonality enable then to reduce the number of setups on the shop floor, thereby decreasing manufacturing and assembly lead times [24]. Other ways to enhance performances and to minimize complexity in an ATO production environment are found in proper assembly sequence planning and assembly system configurations [25,26]. Furthermore, different types of assembly systems (manual, semi or fully-automated) would require specific concerns. In the case of ATO using manual assembly systems (with human assemblers operating usually with the aid of simple power tools [12]), of particular interest for this paper, the presence of human assemblers naturally leads to high potential for "convertibility", as humans qualified and trained may be easily adaptable to new tasks when the demand requires changes; but this potential could still suffer from complexity. In fact, as the product variety becomes high in manual, mixed-model assembly systems, the system performance could be negatively affected by the complexity that is induced, including also the risk that human errors occur [27]. Thus, in order to achieve higher responsiveness, in an ATO production environment, the main concern should be to induce as much flexibility and agility in the system; besides the reduction of complexity on the shop floor should be considered as a key priority.

3 Framework

Literature suggests that "*manufacturing companies adopt different approaches and practices to respond to changing needs from the environment. These approaches and practices induce flexibility and agility in the system and minimize complexity, which ultimately impact different dimensions of responsiveness such as product, process and volume*". Thus, based on literature, a conceptual framework is developed as shown in Figure 1. The framework is composed of different elements in four layers:

- the changing needs emergent from the business environment, for which the manufacturing firms should be capable to be responsive in order to remain competitive;

- the responsiveness and its dimensions to address different needs, also providing a means to classify the determinants of responsiveness;
- the capabilities in a production system based on flexibility and agility that impact different dimensions of responsiveness;
- the manufacturing approaches and practices adopted at operations level, particularly for production planning and system design, that induce/enable flexibility and agility in the production system.

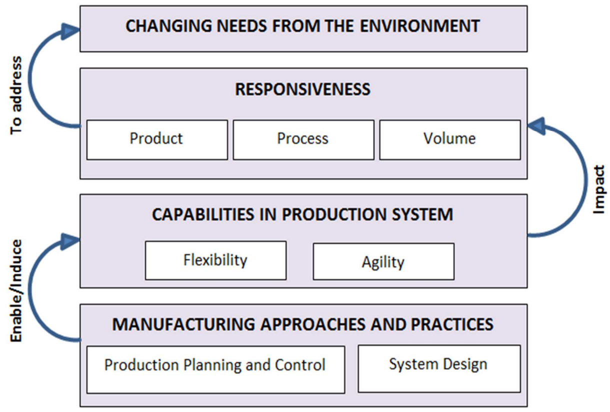

Fig. 1. Conceptual framework

4 Case Study

The case study is analyzed according to the framework developed in previous section. Considered as a leader in its industry, the company manufactures food processing machines for retailers or domestic use. Currently, besides the national market, it fulfills the needs of 125 countries worldwide, including Europe, North America and China. An interesting issue is that, regardless of the wide product variety, the company can deliver finished products within 5 days, achieving high responsiveness.
The key changing needs experienced by the company relate to the product variety and to the quick delivery, with the purpose to be competitive on the global market. Product variety depends mostly on the requests of customization, technical, to cope with local legislations for food equipment, and aesthetic, to maintain the image of the brand. Demand fluctuation is also high, as effect of the mix of customers distributed worldwide and locally. Due to these changing market needs the company decided to change its production strategy, transforming it from the past, Make to Stock (MTS), to the current, ATO. Different practices remarked as relevant for this transformation and for achieving responsiveness are identified in the remainder, reflecting 4 core characteristics of RMS, i.e. customization, convertibility, scalability and integrability.
Customization is based on component standardization and product familiarization, with subsequent effect on the organization of operators in assembly isles, combining high skilled workers – with expertise on a product family, then capable to manage the

variety induced complexity by items within the family –, and low skilled workers – with expertise on the standard components, therefore a task specialization for the first phases of the assembly process.

Convertibility is based on a flexible tracking of information, implemented at the MES (Manufacturing Execution System) level by a decoupled coding system of pallets and components– which supports the ease introduction of new components in the inbound logistics management –, and on the qualification of operators in the shop floor – especially the high skilled operators of assembly isles.

Scalability of inbound logistics and assembly systems is achieved thanks to the adjustment of capacity during the shop calendar day of the picking area, where the assembly kits are prepared, and of the assembly isles: this is possible primarily because the workers, with task specialization on standard components, can rotate amongst different work places.

Integrability is based on the coordinated control of inbound logistics and assembly operations at MES level to achieve the required delivery performance. Firstly, this is achieved by scheduling the automated warehouse to send components in the picking area in close coordination with the assembly program. Secondly, the assembly program execution for batch is based on a work load control principle, being the capacities adjusted so that the assembly lead time of the batch stays within the limits

Overall, it is worth remarking that different types of operational flexibility emerge based on the skills of labor, technological support through a MES of inbound logistics and assembly, product familiarization, and component standardization.

Table 1 summarizes the practices observed for the case, and classified according to the conceptual framework, considering the induced capabilities and their impact on different dimensions of responsiveness; it is worth pointing out that, in some cases, more dimensions are closely connected, since one benefit from the other.

Table 1. Summary of practices, induced capabilities and impact on responsiveness dimensions

Practices	*Induced capability*	*Dimensions of responsiveness*		
		Product	*Volume*	*Process*
Customization based on component standardization and product familiarization + Organization in assembly isles using a mix of skilled operators (for tasks specialization on components and for the whole assemblies within a product family)	Flexibility	√		√
Scalability of inbound logistics and assembly systems, thanks to the adjustment of capacities during the shop calendar day	Agility		√	√
Convertibility based on a decoupled coding systems of pallets and components + qualification / training of assembly operators	Agility	√		√
Integrability based on coordinated scheduling of inbound logistics and assembly + work load control of assembly operations	Flexibility + Agility		√	√

5 Conclusions

The paper, based on literature analysis and a case study, envisions the variables to identify the key characteristics of manufacturing responsiveness. This is aligned with the long term purpose of our investigation, i.e. to understand how SMEs are adapting to provide quick response to changing demands. The proposed framework, and its future developments, will be used in order to drive a systematic analysis of the impact of different approaches and practices on responsiveness; indeed, different dimensions (product, process, volume) and capabilities in the production system (flexibility and agility) will be the leading concepts to this end. The case study presented in the paper is a first test for the framework. Overall, the findings from our investigation – after the extension to different cases – are expected to help SMEs to analyze and adopt different approaches and practices according to their needs, especially concerning the use of proper approaches in ATO strategy. Two particular interests, arising from the case study analyzed in the paper, and worth for future considerations in next cases, can be: i) the customization based on component standardization and product familiarization, to facilitate the introduction of process responsiveness in the shop floor; ii) the integrability of inbound logistics and assembly as a key determinant to guarantee process and volume responsiveness. Further on, considering the social aspect in the SME context, it will be worth concentrating on the role of labor, its support to manufacturing responsiveness, and the achievement of a good balance between economic needs for quick response and social needs of satisfactory working conditions.

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