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NEW SUPPLY CHAIN CONCEPTS, FLEXIBILITY AS A KEY PARAMETER OF AGILE SUPPLY CHAINS

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Abstract: Optimization of supply chains results new models, concepts of value chains and new organization and cooperation forms of members. Nowadays growing market globalization, increasing global competition, more and more complex products requires new production technologies, methods and processes. The product life cycle is getting shorter and shorter, the complexity of final products is increasing and new customer demands require efficient operation of supply chains. Usually three new supply chain concepts are used, the lean, the agile and leagile supply chains. Different manufacturing systems are using these chain concepts, Dedicated Manufacturing Lines (DML) are using lean, Flexible Manufacturing Systems (FMS) agile and Reconfigurable Manufacturing Systems (RMS) are using leagile concepts. In this paper we introduce supply chains and the relating manufacturing systems. We also give an overview of flexibility constraints as an important requirement of nowadays manufacturing, applied in agile supply chains.

1 Supply chain, enterprise, virtual enterprise

Generally, supply chain is a network with different elements, like organizations, activities, resources. Stevens [1], [9] gave a more precise definition, the supply chain is a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together in order to fulfill different customer demands. So concluded that supply chain is a cooperation of business partners driven by business requirements and customers. Due to the fast changing customer demands, market environment and globalization, new supply chain models are developed, like lean, agile and leagile supply chains.

Enterprise is a collection of business processes that combined to produce desired results. Business process is a time ordered set of activities that accomplishes a purpose.

Virtual enterprise is a cooperation of enterprises, which enterprises are the members of the supply chain. It is a virtual temporary alliance between the chain members. The enterprises come together to share their skills, resources, and knowledge in order to better respond to business opportunities [2]. Supply chains and a possible virtual enterprise can be seen in Figure 1. Their main aim is to understand the customer demands and fulfill these fast. These virtual organizations are used in more and more industries, e.g. fashion industry, food industry, automotive industry, etc [3], [4].

Gunasekarana at al. [5] defined that virtual enterprises are characterized by several strategic objectives:

- maximizing flexibility and adaptability to environmental changes,
- developing a pool of competencies and resources,
- reaching a critical size to be in accordance with market constraints, and
- optimizing the global supply chain.

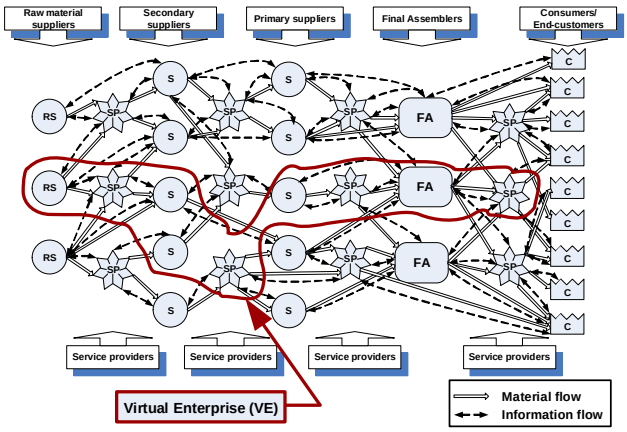

Figure 1 Supply chain networks and a possible virtual enterprise

1.1 Lean Supply Chain

The main goal in a lean organization is to improve the customer value through a perfect value creation process, that has zero waste. It also can be defined to create more

from less, eliminate all wastes, and every non-value adding activities in the whole supply chain process at every member of the chain. The possible type of wastes can be divided in three groups:

1. Unobvious waste.
2. Less obvious waste: it occurs as a result of variability sources such as process time, delivery times, yield rates, staffing levels, and demand rates.
3. Obvious waste: it includes inventory, unneeded processes, excessive setup times, unreliable machines and rework.

Lean is capable of eliminate the obvious waste, and reduce the less obvious waste [6]. This strategy is used usually in mass production, in a stabile, controllable and predictable environment, based on long term trading relationships between the chain members. Usually manufacturing goods with longer life cycle (longer than 2 years), where customer demands are well predictable, and the variety of products is low.

1.2 Agile Supply Chain

The purpose of the agile concept is to quick response to the fast changing market demands. This paradigm relates to the relation between companies and markets. Agile supply chain needs to be flexible and can respond to rapidly fluctuating end customer demands and unpredictable market changing.

One of the first agility definitions comes from the Iacocca Institue of Lehigh University in the United States, they said agility is the ability to cope with unexpected challenges, to survive unprecedented threats of business environment. Agility also has the ability to take advantage of changes as opportunities [7]. Another definition for agility: "it is a business-wide capability that embraces organizational structures, information systems, logistics processes and, in particular, mindsets [8]."

Kidd gave probably the most accurate definition, what is agility in a virtual enterprise. In his opinion agile enterprise characterized by a fast moving, adaptable and robust enterprise, in business market. It also means the enterprise is capable of rapid adaptation in response to unexpected and unpredicted changes and events, market opportunities, and customer requirements.

Agile manufacturing based on three different principles [9]:

- innovative management organization,
- highly trained workers,
- flexible high-tech solutions.

Based on Gunasekaran's definition, agile concept is a vision of manufacturing. It is a result of development process and it is evolved from lean concept. We also can say agility is a business-wide capability that embraces organizational structures, information systems, logistics processes. The key characteristic of an agile organization is flexibility, and the origins of agility can be found in flexible manufacturing systems (FMS).

1.3 Leagile Supply Chain

Leagile concept was developed by Naylor [10]. It is a mixture of lean and agile concepts with their advantages. Using lean techniques, like low production costs as possible, and minimal stocks combining these with the flexibility of agile manufacturing. Leagility is typically applied to the production of "custom-assembled" products, where customer demand forecasts are fairly accurate. In leagile concept innovative technology is used to increase the quality of the produced goods, or ensure uniqueness. This strategy provides an opportunity to produce huge variety of goods with higher manufacturing cost.

2 Comparison of lean, agile and leagile supply chain concepts

Leanness should not be confused with agility, Cristopfer and Towill [8] showed it. Hill [11] developed his own concept for "order qualifiers" and "order winner" criteria. Later in literature other authors changed these terms to market qualifiers and market winners as it can be seen in Table 1. These helps us to make decision which strategy has more advantages in our enterprise. There is borderline between lean and agile concepts, and these order qualifiers and order winner criteria helps to understand it. Lean concept is much stronger than the order winner criteria is cost. This means lean concept is very useful when a company would like to manufacture very similar products in a mass production system. In contrast to lean, agile concept is used when service level is the winner criteria.

Table 1 Difference between lean and agile concepts [8]

Market qualifier strategies	Market winner strategies	
1. Quality 2. Cost 3. Lead Time	1. Service Level	Agile supply
1. Quality 2. Lead Time 3. Service Level	1. Cost	Lean supply

The attributes of lean, agile and leagile supply chains are compared to each other in Table 2.

Table 2 Comparison of lean, agile and leagile concepts [12]

Distinguishing attributes	Lean supply chain
Market demand	Predictable
Product variety	Low
Product life cycle	Long
Customer drivers	Cost
Profit margin	Low
Dominant costs	Physical costs
Stock out penalties	Long term contractual
Purchasing policy	Buy goods
Information enrichment	Highly desirable
Forecast mechanism	Algorithmic
Typical produts	Commodities
Lead time compression	Essential
Eliminate muda	Essential
Rapid reconfiguration	Desirable
Robustness	Arbitrary
Quality	Market qualifier
Cost	Market winner
Lead-time	Market qualifier
Service level	Market qualifier

Distinguishing attributes	Agile supply chain
Market demand	Volatile
Product variety	High
Product life cycle	Short
Customer drivers	Lead-time and availability
Profit margin	High
Dominant costs	Marketability costs
Stock out penalties	Immediate and volatile
Purchasing policy	Assign capacity
Information enrichment	Obligatory
Forecast mechanism	Consultative
Typical produts	Fashion goods
Lead time compression	Essential
Eliminate muda	Desirable
Rapid reconfiguration	Essential
Robustness	Essential
Quality	Market qualifier
Cost	Market qualifier
Lead-time	Market qualifier
Service level	Market winner

Distinguishing attributes	Leagile supply chain
Market demand	Volatile and unpredictable
Product variety	Medium
Product life cycle	Short
Customer drivers	Service level
Profit margin	Moderate
Dominant costs	Both
Stock out penalties	No place for stock out
Purchasing policy	Vendor managed inventory
Information enrichment	Essential
Forecast mechanism	Both/either
Typical produts	Product as per customer demand
Lead time compression	Desirable
Eliminate muda	Arbitrary
Rapid reconfiguration	Essential
Robustness	Desirable
Quality	Market qualifier
Cost	Market winner
Lead-time	Market qualifier
Service level	Market winner

3 Relations between supply chain concepts and different manufacturing systems

Due to digitalization and to the spreading digital enterprise technologies engineers has more opportunities to develop new, to improve and optimize existing manufacturing systems in order to meet customer and logistics demands such as shorter lead time, low stock levels. Nowadays companies which still using Dedicated Manufacturing Lines (DML) systems cannot fulfill these demands quickly, and this encouraged them to develop new technologies. As a result of this process, new systems called Flexible Manufacturing System (FMS) and Reconfigurable Manufacturing Systems (RMS) are developed. These new systems can react to disturbances occurred in supply chains much better and more quickly. The new supply chain concepts and the related manufacturing systems can be seen in Table 3.

Table 3 Supply chains and related manufacturing systems

Supply chain concepts	Manufacturing Systems
Lean supply chain	Dedicated Manufacturing Lines
Agile supply chain	Flexible Manufacturing Systems
Leagile supply chain	Reconfigurable Manufacturing Systems

There is strong connection between supply chains and manufacturing systems. Manufacturing systems can be divided into three main categories. The first one is dedicated manufacturing lines (DMLs). These are mostly designed in order to manufacture only a few variables of products with the highest efficiency. This manufacturing type is very useful for mass producting. The second type is flexible manufacturing systems. These systems produce different kind of parts in lower volume, as Huettemann described [13]. Flexible manufacturing system machines are using more variety and complexity of operations in contrary the machines of DML systems has much more simple operations [14]. Both types have their own properties, DML systems are using lean principle, and FMS is closer to agile manufacturing.

Naylor [10] defined leagility and later Purvis [15] showed her own leagility concept as a mixture of lean and agility. Another type of manufacturing systems has defined by Koren and Shpitalni called Reconfigurable Manufacturing System. This system concept is combining the advantages of DML and FMS, like Naylor combined lean and agile supply chain concepts [16][7]. The most important characteristic of RMS is flexibility, but also focus on low stock limits, and short production times.

4 Flexibility as a key characteristic of flexible manufacturing systems and agile suppl chains

It is important to distinguish different types of supply chain concepts, because all of them has different type of flexibilities, and as a result of this there is a huge difference what flexibility means in lean, agile, and leagile supply chains. Generally, flexibility can be defined as the sensitivity of the manufacturing system to changes for example product variety and production volume changes.

This sensitivity means convertibility and scalability too. It is a metric that can be applied to different types of systems, and focuses on how responsive a system to changes. If a system has a higher level of flexibility, than it can react on much easier to surroundings. In agile supply chains flexibility is one of the most important property, because the systems which are using this concept has to react on the most quickly to customer requirements. The name "agile" is comes from this basic principle and it is a base property of agile supply chain networks, where the members of the chain are cooperating in form of virtual enterprise. The flexibility of an agile supply chain comes from the flexibilities of the chain members, companies.

In literature there is a lot of interpretation of different flexibilities. Vokurka and O'Leary-Kelly defined 15 dimensions of manufacturing flexibility parameters [20]. Oke defined two main categories of flexibility: internal and external flexibility. Internal flexibility describes the system behavior, while external flexibilities effects to the performance of the company. Machine and process flexibility is about how easily we can modify the production, and how to create the same parts in different ways. Operation flexibility is the ability to sequence production in certain ways. Capacity is about how fast we can react when the production capacity is changing. Routing flexibility is an ability to carry on production even we have different stochastic breakdowns in our system [17]. Malhotra refers internal flexibilities as a scope of flexibility which can be achieved without incurring performance penalties [18]. Some other authors defined a lot different flexibilities, for example Naim analyzed transportation flexibility, Zhang examined logistics flexibility as an important factor of customer satisfaction [19].

Purvis summarized in a state of the art article the categories and most cited flexibility parameters, and also suggested a new way to categorize them. She recommended vendor and sourcing flexibility. Vendor flexibility is similar to internal flexibility like Naim suggested, but also includes warehousing and transportation flexibility. Sourcing flexibility referred as an external property and it includes supply network flexibility. In the article a framework has suggested for supply network flexibility [15]. The categorization of most cited flexibilities are in Table 4.

Table 4 Categorization of flexibility parameters based on literature

Oke [21]	Naim [10]		Purvis [15]	
Volume Production Product Delivery	External	Internal	Source	Vendor
	New product Mix Volume Delivery Access	Machine Process Operation Capacity Routing	New product Mix Volume Delivery Organizational	Manufacturing (machine, process, operation, capacity, routing) Warehouse Transportation

Table 5 Our suggested flexibility parameters

Flexibility parameters	
Internal flexibilities	*External flexibilities*
Machine Process Capacity (Re)Routing Operation Material handling Automation	Product Volume Delivery Mix Informatics technology Network relationship

There are a lot of other flexibility categories in literature, almost every author has defined his own ideas for flexibility, but many of them is near the same. We also suggested our categorization based on the earlier presented authors work.

In our categorization we use the terms of internal and external flexibilities, like some other authors suggested it. We complement Naim's internal flexibility parameters with material handling and automation flexibility parameters. The used material handling system which involves such activities as moving, handling, storing gives a very important metric for the manufacturing system flexibility. Automation flexibility is the ability for a robot or system to be quickly and easily re-tasked to change product design for both low and high mix manufacturing. We also add a few new parameters to external flexibility category, like information technology and relationship flexibility parameters. Relationship is willingness to cooperate in order to design and manufacture completely new products. Informatics technology (IT) flexibility is gives us an overview of smooth in competence sharing and its data processing.

Summary

In this paper we gave an overview of the newest supply chain concepts and the connecting manufacturing systems. Agile supply chain as a new supply chain concept which is a result of nowadays globalization and fast changing customer market. Manufacturing companies

has to adopt this concept in order to remain competitive, and to react quickly to customer requirements. Flexibility is a base property of these systems. We introduced the definition and different flexibility parameters based on the literature, and we suggested a new categorization of flexibility parameters and new flexibility constraints. Our suggested flexibilites can be seen in Table 5.

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