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THE STUDY OF AGILITY IN PRODUCTION SYSTEMS AND AGILITY METRICS, MODEL FOR AUTOMOTIVE SUPPLIERS

1. Introduction

Changes in manufacturing conditions resulted to the development of multiple conceptual frameworks at the end of the 20th century. Specialized research publications cite different concepts and principles that are intended to improve the competitiveness of enterprises in global business environment, e.g.: Factory of Future, Intelligent Manufacturing, Agile Manufacturing, Sustainable Manufacturing, Breathing Factory, Excellent Production, Learning Organization etc. [17].
Common feature of those principles are flexible reaction to changing business environment; tendencies to high-tech and orientation to knowledge-based economy [25].
Acceleration of production innovation is attributable to changes in business conditions such as globalisation and growing competition from low cost countries, easier access to knowledge, high technology, changing customer requirements due to the impact of the economic crisis, long-term cost reductions in transport and communications, the importance of growth and performance science and technology, the increasing role of knowledge intensive services, increasing the environmental factors and other.

2. Transition to new management principles – agility

Agility emphasizes the turbulence of today's markets environment. Agility emerged in the USA in 1990 as a program to of enhancements of competitiveness of industry [7]. It is an enterprise-wide strategy with keys characteristics: the customer is the first priority; change is an opportunity to improvement and delivering value.
Companies functioning in ICT area and software market segment have been the earliest adopters of agility in process. They usually iterate numerous versions of programs, and they assess them against customer preferences before the software is ready for mass release. IT firms utilize customer co-development and extensive testing at the beginning of the development cycle [18].
Essential impulses for implementation the conception of agility in enterprises causes [13]: global competition is still intensifying (possibly virtually), mass markets are fragmenting into niche markets, necessary cooperation is present among companies, network- based partnership are created. Nowadays, customers are expecting: low volume products with high quality, custom design, and very short product life cycles. Focuses on customers receive a unique solution, and not just products.
Agile innovative approaches to meet the main needs of industry are:

- Cost-effectiveness, with the adoption of standards in production and inspection equipment and massive use of lean approaches;
- Optimised consumption of resources, efficient use of energy and materials, processes and machines, and intelligent control their consumption;
- Short periods of innovation in the market (from concept to market new products), made possible by information technology – it is necessary including ability to adapt IT systems to support new processes;
- Adaptability and reconfigurability of manufacturing systems to maximize the autonomy and capacity of machines and people interact and use of existing infrastructures;
- High productivity coupled with increased safety and ergonomics, thanks to the integration of technical and human factors.

Characteristic feature of agility in production systems is linked to computer-aided technologies. Those tools enable to get very high speed of response to customer's demands and new market opportunities.

2.1. The scope of agility – definitions and overview

The definition of "agility" accurate expressed by Goldman, Nagel & Preiss: "Agility is dynamic, context specific, focused on aggressive changes and growth oriented. It is not about improving efficiency, cutting costs, or avoidance of competitiveness. It's about succeeding and about winning profits, market share and customers in the very centre of competitive storms that many companies now fear" [2].
Table 1 characterizes the different interpretations of the philosophy of agility, which can be related to the manufacturing systems, as overview of the references scientific publications.

2.2. Reason to Agile Manufacturing

Factories, based on Agile Manufacturing and customisation, are characterized [16] by: future production sites for a large variety of sophisticated products are offering flexible, short cycle time and variability controlling manufacturing capability. These manufacturing approaches ensure energy-efficient, reliable and cost effective production as well as production set-up/ramp-up with reduced cost and time through lean and simpler ICT.
The adaptive (agile) enterprises exploit capabilities to thrive in uncertain and unpredictable business environment. [20] Firms are capable of rapidly responding to changes in customer demand. They are flexible to increase or decrease production volumes through modular and reconfigurable production facilities.
Figure 1 presents the model for explaining the Agile Manufacturing enterprise.
The transformation of enterprise to agile structures requires application of specifics managements tools and techniques e.g.: Knowledge management, Information technology management, Business intelligence, Customer relationship

Approach	Key words explaining agility	Authors
Managerial views	– Combine organization, people and technology into an integrated and coordinated whole to meet the rapid changes in the products and services. – Core competences are derived from a corporate-wide learning process, integration of diverse skills and technologies, work organization, and capability for inter-organizational cooperation.	Abair (2012) [10] Yusuf et al., (1999) [26]
Market views	– Capabilities (hard and soft technologies, human resources, educated management, information) to meet the rapidly changing needs of the marketplace (customers, competitors, suppliers, infrastructure, responsiveness). – Capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets.	Yusuf et al., (1999) [26] Gunasekaran (2002) [14]
Systemic views	– Emend of speed, flexibility, innovation, quality, proactively and profitability through the integration of reconfigurable resources that must be achieved in synergy. – Quickly react to change by re-configuration of products, processes and organization structure.	Yusuf et al., (1999) [26] Dove (1993) [11]
Technological/ operational views	– Include virtual enterprise formation tools, physically distributed manufacturing architecture and teams; rapid partnership formation tools; concurrent engineering; integrated product/ production/ business information system; rapid prototyping; electronic commerce. – Modular production facilities that can be organized into ever changing manufacturing nodes.	Gunasekaran (2002) [14] Ferris (2002) [13]
Organizational views	– Core skills or competencies of enterprises they bring to a joint venturing operation, which is based on using each partner's facilities and resources. – It is necessary to utilize all existing resources regardless of their location and cooperate internally and with other companies; effective mastering of change requires flexible organizational structures that allows for rapid reconfiguration of the human and physical resources.	Kidd (1994) [19] Goldman et al., (1995) [2]

Tab. 1. Interpretation of agility in different definitions

management, Supply chain integration management, Outsourcing, Collaborative development, Entrepreneurial environment modelling, Crisis management, E-learning at best practices, Decentralized management and Virtual organization management [23].

2.3. Lean vs. Agile manufacturing approach

Today, manufacturing companies in their management strategies emphasize of lean principles. Lean principles are particularly dominant in automotive production. Non-production oriented enterprises sequentially take over this concept of management [4].

We analysed the key issue of relationship management approach Lean vs. Agile:

- Principles Lean and Agile are controversial, i.e. agile concept replaces of Lean?
- Can those approaches to business process management exist simultaneously?
- Is agile conception one of extension of Lean?

Attention of Lean philosophy of managing manufacturing operations is primarily focused to eliminate all activities that do not add any value. Agile management concept emphasizes the company's ability to respond quickly to new customer's orders and changes in market. Agile manufacturer is generally able to quickly change the layout of production facilities, in order to promptly support the new demand. It focuses on the removal of technical and organizational barriers that prevent achieving a degree of flexibility that is able to adapt very quickly to large and fundamental changes in business process, including the supply chain network.

Management of the manufacturing company prefers the concept of Agility, if:

- range of their products is growing significantly, because from their customers, there is considerable demand for alternatives and versions;
- it is impossible to predict demand in advance.

Management of the manufacturing company prefers the procedure of Lean, if:

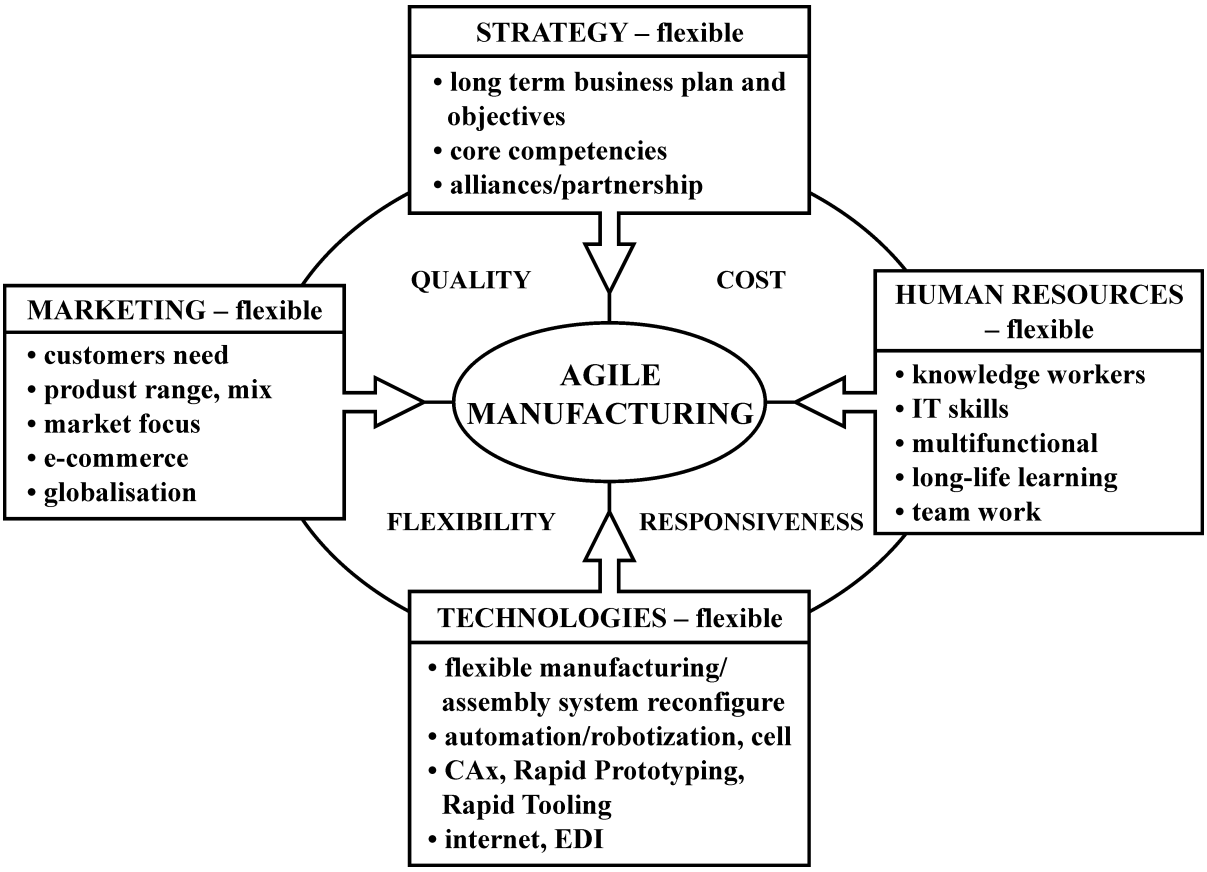

Fig. 1. Agile manufacturing model (author's adaptation according to [14])

- range of manufactured products is closed, preferably in large quantities;
- demand is predictable.

The characteristics of "Lean" are extremely important for understanding of "Agile". Agile manufacturing is a continuation of the concepts of flexible and Lean manufacturing. Lean production is methodology developed originally for Toyota (it is known as the Toyota Production System) [6]. The goal of Lean production was initially described as "to get the right things to the right place at the right time, the first time, while minimizing waste and being open to change" [8]. In addition to eliminating waste, this concept led to improved of product flow and better quality. The techniques of Lean are focused on reducing system response time so that the production system was capable of immediately changing and adapting to market demands; products became made-to-order [9].

Lean Manufacturing provides continually reducing lot sizes, lead-times, errors, and all unnecessary activities that add cost but not value [5]. Lean manufacturing is a business philosophy that continuously shortens the time between customer order and shipment by eliminating everything that increases the cost and time [1].

Lean production is also a different concept to Agile manufacturing, as show results described in Table 2.

To be Agile, organizations must be Lean as a prerequisite. Agile might be viewed as the next wave after Lean and most of the requirements for Lean are also requirements for Agile [12].

Scheme at Figure 2 shows different elements aimed at Lean production and Agile manufacturing firms' orientation. Only when it is not possible or not cost effective at the moment have in operation continuous material flow is there a compromise allowing for buffers or separation of production processes.

Agile manufacturing is a vision of manufacturing that is a development from the concept of Lean production. In Lean production, the emphasis is on the elimination of sources of waste. "Lean" implies high productivity and quality, but it does not necessarily imply being responsive to unique customers' demands. "Agile" stresses the importance of being highly responsive to meet the 'total needs' of the exact customers [14].

Figure 3 presents the model for evaluation Agile Manufacturing and Lean Manufacturing preference.

The agile manufacturing system should be able to produce a variety of components in a short time period. To achieve Agile Manufacturing status, companies primarily need implement Agile design processes. Agile product development system is capable of addressing frequent iterations of multiple design options early in the process, based on continuous testing and highly sophisticated customer-driven design changes [18].

3. Agility in automotive production

Automobile manufacturing is a significant example of innovative changes. In particular: In addition to the impact of

Characteristics – LEAN	Characteristics – AGILE
– is a response to competitive pressures with limited recourses,	– is a response to complexity brought about by constant change,
– is bottom-up driven, incrementally transforming the mass-production model,	– is top-down driven responding to large forces,
– is a collection of operational tactics focused on productive use of resources,	– is an overall strategy focused on thriving in an unpredictable environment,
– brought flexibility with its alternate paths and multiuse work modules,	– brings reconfigurable work modules and work environments,
– is process focused.	– is boundary focused.

Tab. 2. Comparison of lean and agile manufacturing principles (author's adapted according to [12])

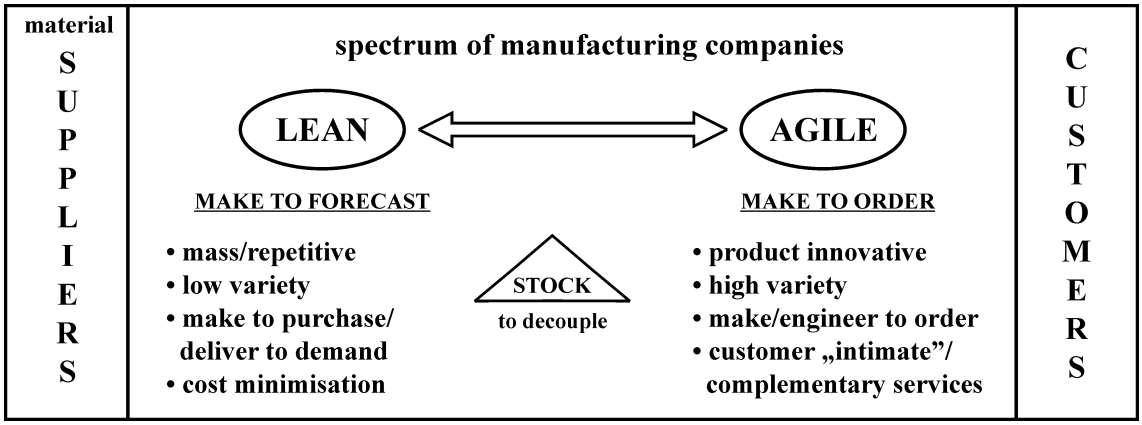

Fig. 2. Model of the main characteristics of production systems (author's adaptation)

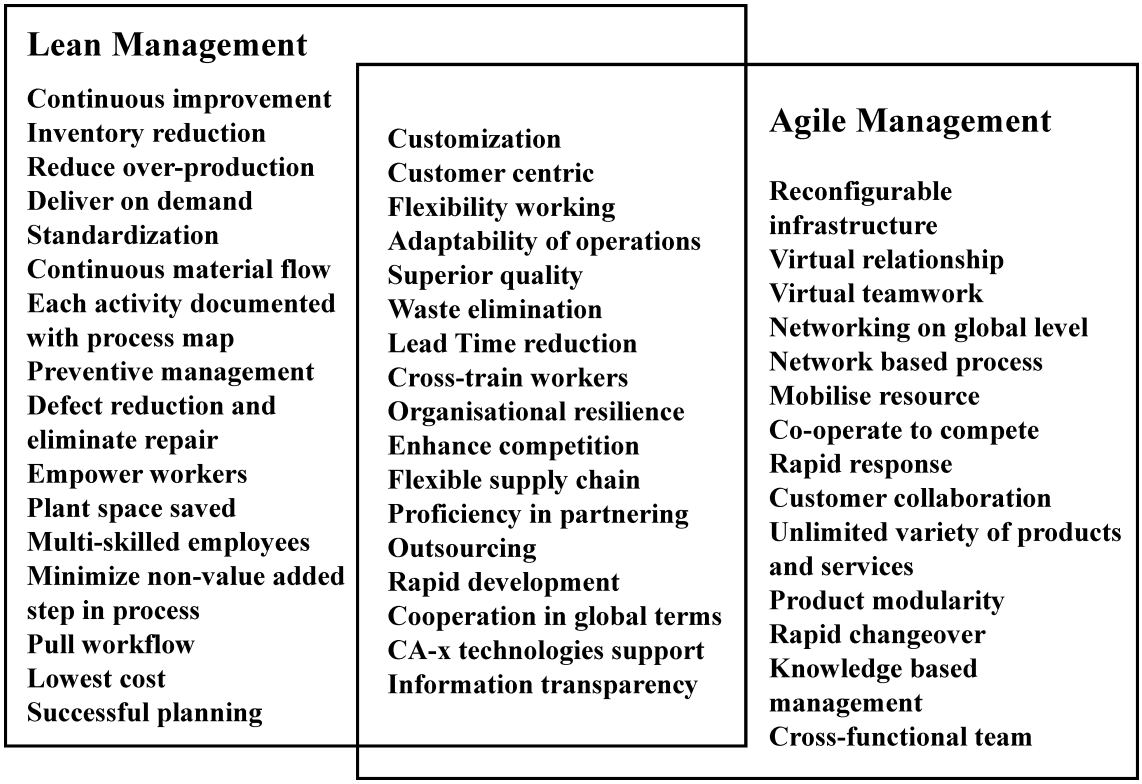

Fig. 3. The model of common principles in business management forms Lean and Agile Manufacturing (author's adaptation)

financial crisis on the automotive industry are also other important factors that determine innovation. In particular:
- A change in customer preferences. Currently, the highest preference among customers are low consumption and operating costs, reasonable price and quality;
- Radical change in markets where the growth centres are shifting to new markets (BRIC - China, India, Russia, Brazil);
- The existence of excess production capacity on saturated markets;
- Environmental factors that accumulate legislative standards;
- Technological opportunities: electric mobility, communication systems, advanced safety systems;
- Radically shortening innovation cycles to differentiation of major types of cars.

The need and extent of the changes in automotive production shows potential for intensive implementation of agile approaches. To study the requirements for agility, it is useful to define the type and stage of development and production activities, which shows Figure 4.

The potential for Agility is in all stages of the innovation cycle of automobile production. Condition and intensity of Agility are differentiated in the various activities.

The automotive industry applies a modular architecture, allowing automakers to expand model lines and introduce new versions of vehicles. Use of platform components and related models of components increases productivity and also innovation flexibility. Trends in vehicle design and assembly such as shared platforms and modules help reduce the complexity of final assembly. This helps to achieve a simpler assembly on multi-product lines, resulting in a more flexible build to order system.

Agile automotive manufacturing requires a rapid changeover from the assembly of one product to the assembly of a different product. It is necessary develop and integrate technologies that will facilitate the vehicle assembly process into becoming self-adaptive to any kind of market variation and capable of producing cars with extended degree of personalization.

4. Model of agility metrics in the supplier company of automotive manufacturing

Metrics are used in different areas to assess the level of systems and processes defined by a set of quantitative and qualitative rate. In the published literature are more general models for agility metrics, such as [11].

Our research is focused on the creation of specialized models, particularly for automotive suppliers. Differ in this sector is the emphasis on agility R & D and technology, because many parameters automotive suppliers standard meet automotive agility (quality standards, flexible delivery).

Model metrics in our study is based on the following principles:
- Criteria to compare with other types of agility metrics (e.g. Lean, Innovation,);
- Flexibility for different conditions of business environment and manufacturing sectors;
- The activation effect on the actual business metrics for the necessary changes.

Our research in suppliers of automotive production forms a model for the assessment of the agility, which: respects the generally accepted metrics of innovation production enterprises, SMEs conditions and specific characteristics of automotive production. The model consists of a set of modules that analysed and evaluate potential business agility (Fig. 5).

Modules are defined as portfolio metrics. The unification of different evaluation indicators methodology is used to transfer point scale, where:
- The lower limit – 0 points is equivalent to a minimum or absence of parameters analysed;
- The upper limit – 10 points corresponds to the value of the parameter leadership agility.

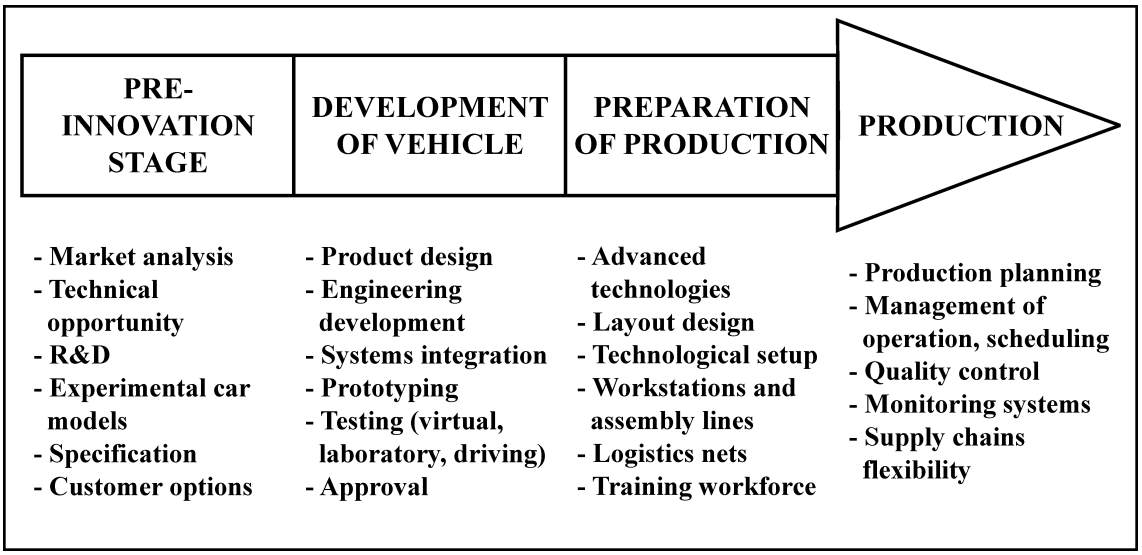

Fig. 4. Model of innovation activities in the automotive industry (authors background papers [22])

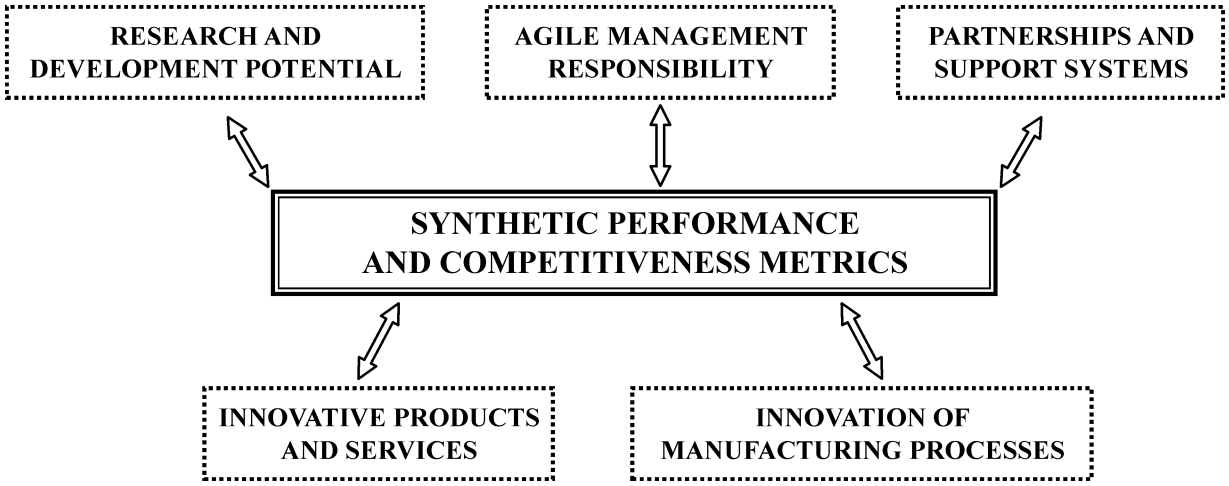

Fig.5. Model agility metrics for automotive suppliers (own processing)

Overview of the evaluation agility metrics in modules:

1 Module: Research and Development potential

1.1 ***The level of R&D technical equipment*** (Laboratory, testing devices, prototype workshops, rapid tooling and prototyping etc.);

1.2 ***The level of knowledge - based tools for R&D*** (Design for manufacturing and assembly, simulation and virtual testing, computer aided engineering, reverse and simultaneous engineering, collaborative engineering, virtual engineering, creative innovation techniques etc.);

1.3 ***The capacity of R&D*** (Capacity as % of assets, % of workers in R&D, % of sales spent on R&D etc.);

1.4 ***Time to market*** (Duration of the development cycle);

1.5 ***The performance of R&D*** (% frequencies or number of new products, technology and organizational change implementation etc.).

2 Module: Agile management responsibility

2.1 ***Rapid response to changing market requirements*** (Modelling of customer behaviours, knowledge assessment tools to market demand scenarios, multi-venturing capabilities etc.);

2.2 ***Embracing a culture of change*** (Decentralisation of organization…);

2.3 ***The level of implementation of lean management*** (Elimination of overproduction and excess inventory and capacity, redundant operations, total productive maintenance, continuous material flow, JIT deliveries, Kaizen principles etc.);

2.4 ***Human Resource Development for Agility*** (Multi-skilled and flexible workforce, continuous workforce skill upgrade training, job rotation etc.);

2.5 ***Rapid formation of partnerships*** (Strategic relationships with customers, suppliers, co-operators, research partners and business cooperation - share of production cooperation, sub-capital links, consortium, joint venture etc.);

2.6 ***Participation in innovation networks*** (Innovation centres, centres of excellence, cooperation with universities, clusters, technology platforms etc.).

3 Module: Innovative products and services

3.1 ***New products implementation*** (% of product portfolio in the last 1, 2, 5 years…);

3.2 ***The level of customer satisfaction*** (Design/ quality and reliability, safety/ quality and environmentalist standards prescribed in the manufacturing sector etc.);

3.3 ***The technological level of new product*** (Level of manufacturability, the impact on capacity utilization, suitability for high technology, the possibility of manufacturing automation etc.);

3.4 ***The level of competitive products*** (Certification of products for global markets, the use of product platforms, meet new customer needs etc.);

3.5 ***Suitability for delivery in the network*** (JIT deliveries, packaging, supply chain information etc.).

4 Module: Innovation of manufacturing processes

4.1 ***The level of flexibility in production*** (Volumes and product range…);

4.2 ***Highly reconfigurable manufacturing and logistics systems*** (Flexible, capable of immediate operation etc.);

4.3 ***Ability for production system reinstalled*** (Anywhere in the world, without lengthy start-ups and additional costs etc.);

4.4 ***Flexible, customisable effectors and tooling systems*** (The dynamic system of exchange of instruments, fully digital machine set up and operation etc.);

4.5 ***High performance, and high-tech cells and lines*** (Accuracy - higher speed machines, mechatronic devices, robotics, CAM systems, healthy and safe operating man-machine interaction, ergonomics work stations etc.);

4.6 ***The level of information technology application*** (CAx - CAP, ERP systems, a stockless supply management system in just-in-sequence, Electronic Data Interchange (EDI) systems etc.);

4.7 ***New technology introduction*** (% of technology portfolio in the last 1, 2, 5 years…).

The procedure for calculating the synthetic parameter enterprise agility:

1. Selection of relevant parameters for real agility business environment.

2. Benchmarking the parameters for agility in the average of leading companies.
3. Expert scoring parameters of business agility.
4. Synthesis of overall agility parameter.
5. Identification of critical parameters and preparation of innovative program.

Future research is aimed at testing the model in enterprises combining opinions of managers and business experts. This allows determining coefficient of significance of each parameter of agility.

5. Conclusion

Compared to the past, customers require notably higher quality and faster delivery times. This pushes firms towards higher flexibility and permanent adaptation of machines, equipment and production systems as well as supply chain system and infrastructure elements. To meet these challenging requirements high performance manufacturing in terms of efficiency and accuracy is the key. Agility offers great potential for business growth also in automotive industry.

The authors have long engaged in the research innovation in automotive production. At this time does the project "Product design for high-tech production systems and risk management of innovative projects" (ITMS: 26220120060), which is part of the "Excellence centre" project at the Faculty of Mechanical Engineering, Technical University of Košice. The project activity is aimed at the new knowledge and methodologies of implementation in practice for innovation in designing and implementation of production systems, high-tech products and the development of knowledge-intensive services to eliminate the risk of innovative projects.

The project also includes research on the implementation of agile techniques in the design of cars and their production. Our research study that we have created has shown that there is a general base of knowledge for transformation of selected enterprises to agile production systems if they are applied Lean management principles and technologies. In the next period we plan to examine the differentiation of processes implementation of agility of the following aspects:

- Sequence of phases of agile management, product development, technology, supply chain, marketing and post-production services;
- Determining of agility metrics in time periods of reengineering stages to optimise the investment risks.

The authors welcome collaboration with other partners, as project implementation agility of manufacturing systems requires the integration of knowledge in cooperative networks.

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Key words:
Agile manufacturing, lean manufacturing, flexibility, agility in automotive, agility metrics

Abstract:
This article deals about the challenges of structural innovation in production systems. Changes in manufacturing conditions resulted to the development of multiple conceptual frameworks. The topic of agility in management is associated with the reaction of changing business strategy under the conditions of knowledge based economy. Introductory section of the paper presents the scope of agility, provides definitions of Agile Manufacturing by various authors, and focuses on providing an overview of Agile Manufacturing characteristics. In the next part of the article is compared approach to Lean Manufacturing and Agile Manufacturing. To be Agile, organizations must be Lean as a prerequisite. Lean production is also a different concept to Agile Manufacturing. Agile might be viewed as the next wave after Lean and most of the requirements for Lean are also requirements for Agile. Another part of the article analyses the agility trend in automotive industry. The potential for Agility is in all stages of the innovation cycle of automobile production. In the final part of the article is presented our research to the creation of metrics for measurement of agility automotive suppliers. In this section of the paper are summarized key elements of Agile automotive production system. Formulated is a set of modules and parameters and approach their application. The transformation of enterprise to agile structures requires application of specifics management's tools and techniques. Agility offers great potential for business growth when global competition is intensifying and mass markets are fragmenting into niche markets.

STUDIUM POJĘCIA AGILE MANUFACTURING W SYSTEMACH PRODUKCYJNYCH, WSKAŹNIKI AGILNOŚCI DOSTAWCÓW DLA ZAKŁADÓW BRANŻY MOTORYZACYJNEJ

Słowa kluczowe:
przemysł motoryzacyjny, Agile Manufacturing (zwinna produkcja), Lean Manufacturing (odchudzona produkcja), wskaźniki agilności produkcji

Streszczenie:
W części wprowadzającej do artykułu przedstawiono współczesne tendencje rozwoju procesów zarządzania procesami produkcji.
W następnej części opracowania porównano podejście filozofii Lean Manufacturing i Agile Manufacturing (odchudzonej i agilnej albo inaczej zwinnej produkcji) w procesach zarządzania przedsiębiorstwem. Kolejna część artykułu analizuje trendy agilności w zakładach przemysłu motoryzacyjnego. W końcowej części artykułu przedstawiono wyniki własnych badań, związanych z tworzeniem wskaźników określających agilność produkcji na przykładzie dostawców dla przedsiębiorstw przemysłu motoryzacyjnego.

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