TEKES – Uudistuva teollisuus -aktivointihanke

Competitive and sustainable production systems and networks (KEKE)

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WP 5 – Discussion on Lean, Agile and Sustainable production factors

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Introduction

This report discusses on factors influencing design, development, and operation of manufacturing systems. The aim is to classify the factors to form a basis for assessing and improving manufacturing systems in that the gathered information and knowledge can be reused in different cases. This at its best gives a more holistic view for decision making and reduces the risk of not taking any important factor into consideration when the future activities are decided. The factors are considered from the viewpoints of Lean, Agile, and Sustainable Manufacturing, categorized into portions of a proposed structure of manufacturing systems i.e. business, products, processes, resources, production, and orders. This division then serves the aim to describe the factors more explicitly, which is one of the key issues to be able to utilize the information using computer aided technologies. As an example, the factors are discussed in more detail in the context of factory simulation.

This research centers on typical Finnish mechanical engineering industry, i.e. discrete part manufacturing for business-to-business (B2B) industry. The focus of the research is on an individual factory floor existing in a supply network. These typically include part manufacturing, procurement, and product assemblies.

The end-products are typically highly customized and tailored to customer needs and requirements with low or medium demand (Lapinleimu, 2001). Even when the focus of this report is mainly at individual factories, the research is conducted in the way that the findings can be adapted to consider a whole supply network.

Background

The research builds on previous research and experience in the areas of Lean and Agile Manufacturing as well as using the tools and principles of Digital Manufacturing in aiding the design and development activities of manufacturing systems. A more recent area for the authors is Sustainable Manufacturing, a crucially significant issue when determining future competitive measures and success factors for companies.

The philosophy and practices of Lean manufacturing aim at efficient manufacturing processes and at high, consistent quality by eliminating non value adding operations, standardising processes, and continuous improvement (Womack et al., 1990). The core idea is to maximize customer value while minimizing waste, and to create more value for customers with appropriate resources (Lean Enterprise Institute, 2008). The definitions of Agility and Agile manufacturing emphasise the need to adapt to changes in the business environment and generally agility is defined as the ability to both react to and take advantage of changes and opportunities (Sharifi and Zhang, 1999). For example, Gould summarises that agility is the ability of an enterprise to thrive in an environment of rapid and unpredictable change (Gould, 1997).

Competitive and Sustainable Manufacturing

The well-known definition of sustainability is: “The Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). This political statement is the root cause for today’s key global challenges and related problems that call for a drastic change of paradigm from economic to sustainable development. Competitive Sustainable Manufacturing (CSM) is seen as a fundamental enabler of such change (Jovane, 2009).

Sustainable development has been recently increasingly emphasized around the world; in Europe (Factories of Future Strategic Roadmap and the Manufuture initiative), the USA (Lean and Mean), and Japan (Monozukuri and New JIT). The CSM paradigm widens the classical view of sustainability to interact with the Social, Technological, Economical, Environmental, and Political (STEEP) context (AdHoc, 2009). Sustainable manufacturing is a multi-level approach where product development, manufacturing systems and processes as well as enterprise and supply chain levels need to be considered, with metrics identified for each level (Jawahir et al., 2009).

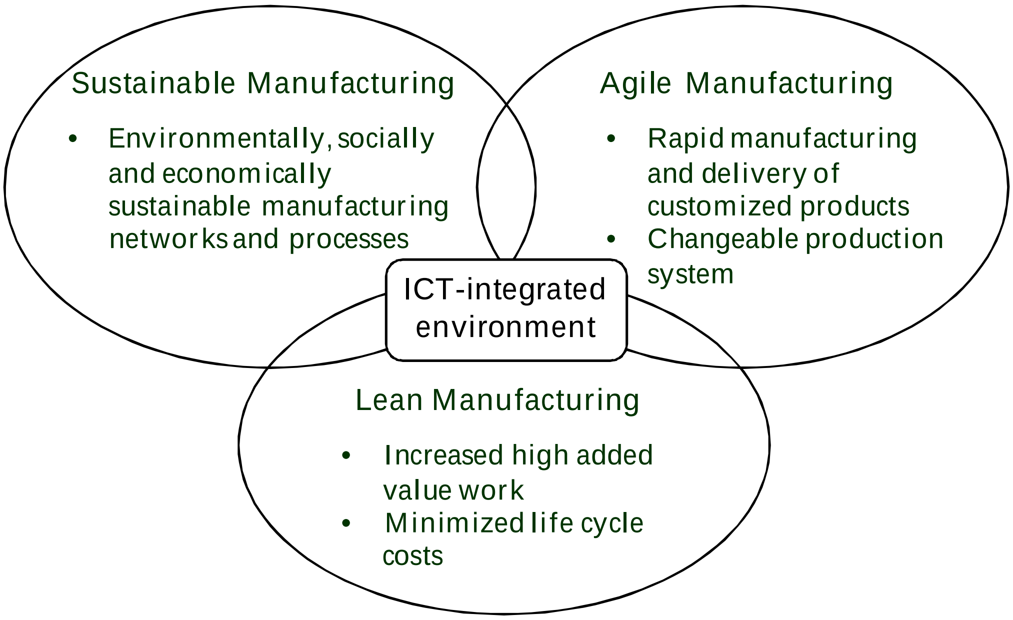

Figure 1. The cornerstones of the CSM at the Department of Production Engineering (Nylund et al., 2010)

The CSM is one of the strategic research areas within the Department of Production Engineering (TTE) at Tampere University of Technology (TUT). Figure 1 presents the main areas of the CSM approach, consisting of three main pillars, Sustainable, Lean and Agile Manufacturing. Lean manufacturing aims to combine the advantages of craft and mass production, while avoiding the drawbacks such as the high costs of craft production and rigidity of mass production systems (Womack et al., 1990). For example, the Lean Enterprise Institute (2008) defines Lean manufacturing as “a business system for organizing and managing product development, operations, suppliers, and customer relations that requires less human effort, less space, less capital, and less time to make products with fewer defects to precise customer desires, compared with the previous system of mass production."

Agile manufacturing can be defined as an enterprise level manufacturing strategy of introducing new products into rapidly changing markets (Nagel & Dove, 1991) and an organizational ability to thrive in a competitive environment characterized by continuous and sometimes unforeseen change (Kidd, 1994). Agile manufacturing highlights the need to adapt to changes in the business environment, and generally agility is defined as ability to react to and take advantage of changes and opportunities, see for example (Sharifi & Zhang, 1999; Gould, 1997).

Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). It consists of three structural pillars namely society, environment, and economy, whilst at the same time it also involves operational aspects such as the consumption of resources, natural environment, economic performance, workers, products, social justice and community development (Jayachandran et al., 2006). When these three pillars of Lean, Agile, and Sustainable are considered as one system, Lean emphasized the stability of a system that can be referred as the autonomy while agility adds the needed capability to change to new situations, therefore focusing more on the collaboration. These two have their main focus on economic issues while sustainability adds the viewpoints of energy and environmentally friendly manufacturing.

Support from Digital Manufacturing

The tools and principles of digital manufacturing, factories, and enterprises can offer significant value to all aspects of manufacturing systems during their life cycles. However, there are no commonly used or agreed definitions for those, but they usually share the idea of managing the typically isolated and separate manufacturing activities as a whole by the means of Information and Communications Technology (ICT) (Nylund and Andersson, 2011). Typical examples often found from the definitions, based on literature, are (see, for example: Bracht & Masurat, 2005; Maropoulos, 2003; Souza et al., 2006):

- An integrated approach to develop and improve product and production engineering technologies.
- Computer-aided tools for planning and analysing real manufacturing systems and processes.
- A collection of new technologies, systems, and methods.

Typical tools and principles of digital manufacturing on different structuring levels are, for example (Kühn, 2006):

- Computer-aided technologies, such as computer-aided design (CAD) and computer-aided manufacturing (CAM), e.g. offline programming for virtual tool path generation to detect collisions, analyse material removal and optimise cycle times.
- Visual interaction applications, e.g. virtual environments and 3D-motion simulations that offer realistic 3D graphics and animations to demonstrate different activities.
- Simulation for the reachability and sequences of operations as well as internal work cell layout and material handling design. These include, for example, realistic robotics simulation (RRS) and ergonomics simulation.
- Discrete event simulation (DES) solutions including the need for and the quantity of equipment and personnel as well as evaluation of operational procedures and performance. DES can also be focused on e.g. factories and supply chain or network sales and delivery processes as well as to complex networked manufacturing activities, including logistical accuracy and delivery reliability of increasing product variety.

The above are examples of typical application areas of digital manufacturing. In each case, the activities rely on up-to-date and accurate information and knowledge. The total information and knowledge of a manufacturing system can be explained with explicit and tacit components (Nonaka and Takeuchi, 1995). The explicit part of the knowledge can be described precisely and presented formally in ICT-systems. The skills of humans are explained as the tacit dimension of knowledge, which, presented digitally, may lead to unclear situations and can be wrongly understood. The importance of the transformation from tacit to explicit knowledge has been recognized as one of the key priorities of knowledge presentation (Chryssolouris et al., 2008).

Challenges exist both in the autonomous and collaborative parts of the digitally presented manufacturing entities. The internal part should include only the needed information and knowledge to fully describe the autonomous activities while the collaboration mostly relies on effective sharing of information and knowledge and therefore both the communication language and content should be described formally. Effective knowledge management consists of four essential processes: creation, storage and retrieval, transfer, as well as application, which are dynamic and continuous phenomenon (Alavi and Leidner, 2001). Examples of the application areas of the digital part are:

- Email messages, Internet Relay Chat (IRC), Instant Messaging, message boards and discussion forums.
- More permanent information and knowledge derived from the informal discussions, stored in applications such as Wikipedia.
- Internet search engines and digital, such as dictionaries, databases, as well as electronic books and articles
- Office documents, such as reports, presentations, as well as spreadsheets and database solutions.

- Formally presented information systems, such as Enterprise Resource Planning (ERP), Product Data Management (PDM), and Product Lifecycle Management (PLM).

The importance of the possibilities offered by ICT tools and principles is ever more acknowledged, not only in academia, but also in industry. The Strategic Multi-annual Roadmap, prepared by the Ad-Hoc Industrial Advisory Group for the Factories of the Future Public-Private Partnership (AIAG FoF PPP), lists ICT as one of the key enablers for improving manufacturing systems (AdHoc, 2010). The report describes the role of ICT at three levels; smart, virtual, and digital factories.

- Smart factories involve process automation control, planning, simulation and optimisation technologies, robotics, and tools for competitive and sustainable manufacturing.
- Virtual factories focus on the value creation from global networked operations involving global supply chain management.
- Digital factories aim at a better understanding and the design of manufacturing systems for better product life cycle management involving simulation, modelling and management of knowledge.

Both digitally presented information and knowledge as well as computer tools and principles for modelling, simulation, and analysis offer efficient ways to achieve solutions for design and development activities. General benefits include, for example:

- Experiments in a digital manufacturing system, on a computer model, do not disturb the real manufacturing system, as new policies, operating procedures, methods etc. can be experimented with and evaluated in advance in a virtual environment.
- Solution alternatives and operational rules can be compared within the system constraints. Possible problems can be identified and diagnosed before actions are taken in the real system.
- Modelling and simulation tools offer real-looking 3D models, animations, and visualisations that can be used to demonstrate ideas and plans as well as to train company personnel.
- Being involved in the process of constructing the digital manufacturing system tasks increases individuals’ knowledge and understanding of the system. The experts in a manufacturing enterprise acquire a wider outlook compared to their special domain of knowledge as they need to gather information also outside their daily operations and responsibilities.

Definitions

Definitions of Lean Manufacturing

The term "lean production" was coined in the beginning of 1990's in the book "The Machine that Changed the World". Its roots are in the Japanese manufacturing tradition, especially at the Toyota Motor Corporation, but it has evolved to be one of the most important manufacturing paradigms also in the Western countries (Hines et al. 2004, pp. 994-995). The development of lean production started in Japan after the World War II. The need for new manufacturing approach was caused by scarcity of resources and materials, reduced work force, intense domestic competition and serious financial shortages (Hines et al. 2004, p. 994; Sickler, p. 4). The growing pressure to become efficient, effective and more competitive, on one hand, and the significant differences, revealed in the book the Machine that Changed the World, in performance between the Japanese and western manufacturers on the other hand have encouraged the western companies to adopt lean philosophies and practices (Radnor & Boaden 2004, p. 425; Hines et al. 2004, p. 994). Since the introduction of the term, the strategic issues, in addition to techniques and solutions, have received more attention and also the scope of lean production has been widened to cover the entire supply chain, not only one factory (Radnor & Boaden 2004, p. 425; Womack & Jones 1994, pp. 93-94). The reason for focusing more on these issues is that otherwise the full potential of lean principles can not be utilised.

Definitions and objectives

Generally the definitions of lean production emphasise the ability to produce more with less resources when compared with the traditional mass production. According to Radnor & Boaden (2004, p. 425) the term lean production has evolved from describing the production techniques used by the Japanese to provide a more holistic view of the manufacturing system. For example, the Lean Enterprise Institute (LEI) defines lean production as "a business system for organizing and managing product development, operations, suppliers, and customer relations that requires less human effort, less space, less capital, and less time to make products with fewer defects to precise customer desires, compared with the previous system of mass production." (Anon. 2004). When introducing the term "lean production", Womack et al. (1990) stated that it aims to combine the advantages of craft and mass production, while avoiding the drawbacks such as high cost of craft production and rigidity of mass production system. According to Hines et al (2004, pp. 994-996), typical to lean production is the focus on creating value to the customer and on eliminating waste and excess from the product flows, i.e. production processes (Hines et al. 2004, pp. 994-996). Similar characteristics are presented in the definition of lean enterprise, which considers the whole supply chain: "lean enterprise is a group of individuals, functions, and legally separate but operationally synchronized companies. The notion of the value stream defines the lean enterprise. The group's mission is collectively to analyse and focus a value stream so that it does everything involved in supplying a good or service (from development and production to sales and maintenance) in a way that provides maximum value to the customer" (Womack & Jones 1994, p. 93).

The objectives of lean production, as can be seen from the definitions, are to create value to the customer and at the same time obtain low cost, high variety, high quality, and very rapid throughput times to respond to changing customer desires (Womack 2002; Karlsson & Åhlström 1996, p. 25). Womack et al. (1990) also emphasise that lean producers strive for perfection with help of continuous improvement. The improvements are aimed at reducing costs, eliminating waste and achieving zero levels of defects and inventories (Karlsson & Åhlström 1996, pp. 27-30; Booth 1996, pp. 106-107). In relation to creating value to the customer, Hines et al. (2004, p. 997) have identified two ways that should be considered:

- Increasing the overall value proposition for the customer by reducing internal waste and the associated costs
- Increasing value by offering additional features or services, which are valued by the customer.

Womack and Jones (1994, p. 103) have also considered the objectives and benefits of lean enterprises from the perspective of economy as follows: “An economy dominated by lean enterprises continually trying to improve their productivity, flexibility, and customer responsiveness might finally be able to avoid the kind of social upheavals that have occurred when new production systems have rendered existing ones obsolete. … Equally important, we will witness a productivity explosion, coupled with employment stability, that will provide the long-sought antidote to the economic stagnation plaguing all advanced economies.”

Naylor et al. (1999, p. 108) have presented the following definitions for agility and leanness:

- “Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place.”
- “Leanness means developing a value stream to eliminate all waste, including time, and to ensure a level schedule.”

Based on these, Mason-Jones et al. (2000b, p. 54) conclude that the difference between lean and agile manufacturing is that in a lean manufacturing environment the demand should be smooth, leading to a level schedule, while agile manufacturing can operate in a volatile market place. Mason-Jones et al. (2000a, p. 4065) have also introduced a new term, leagility, which combines the lean and agile paradigms by positioning the decoupling point (the point which separates the part of the supply chain oriented towards customer orders from the part which operates based on planning) in the supply chain so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the marketplace. The objective of leagility is to maximise profits by combining the advantages of lean and agile manufacturing in the following manner: leanness will maximise profits through cost reduction and providing service suitable for a level schedule, while agility maximises profit through providing exactly what the customer requires and reducing costs whilst not impeding the ability to meet the customer service requirements (Mason-Jones et al. 2000b, p. 59)

Prerequisites for implementing lean production

Many authors (e.g. Hines et al. 2004, Sickler 2004) stress the importance of strategic view and approach to implementing lean production and state that too often lean production only regarded as a set of tools and techniques. Sickler (2004, p. 5) summarises the requirement of broader view and commitment well in the following: "If a company is serious about becoming Lean they must be totally committed to implementing the Lean philosophy in all aspects of their operation and they must be just as devoted to the belief that Lean implementation is a never ending process. Far more than manufacturing, Lean is a business philosophy that evolves from its own application and it is not just a set of rules or a cook book of instructions. Lean can only be made to truly work when it becomes a way of doing business that is applied across all operations, from the operator level to the executive decision making process."

Womack and Jones (1994) have discussed extending lean production to lean enterprise that covers the whole supply chain. Achieving this entails, according to them, radical changes in employment policies, the role of functions within companies, and the relationships among the companies of a value stream. Managers will have to concentrate on the performance of the enterprise rather than on the performance of individual people, functions, and companies. (Womack et al. 1994, p. 94) When implementing lean enterprise, the following needs of individuals, functions and companies must be addressed:

- Needs of the Individual, such as job, career and development
- Needs of Functions. Functions are places where learning is collected, systematized, and deployed and therefore they need a secure place in any organization.
- Needs of Companies such as ability to calculate costs and the benefits it generates and see the results of its improvement efforts.

Proposed solutions and frameworks

Various authors have presented typical characteristics of lean production systems and also frameworks for designing or developing a lean production system. Toyota has been identified as the creator and the most advanced practitioner of lean production, hence the Toyota Production System (TPS) is often used as an example or a reference of a lean production system. Here, firstly the characteristics of lean production or TPS are reviewed and then various frameworks for designing a lean production system are presented.

General characteristics of lean production system

Karlsson and Åhlström (1996, pp. 27-39) focused mainly on manufacturing function of lean production and lean enterprise and identified the following typical or characterising principles:

- Elimination of waste, which requires eliminating everything that does not add value to the product and customer in order to reduce costs and use of resources.
- Continuous improvement aiming at perfection.
- Zero defects, i.e. producing and using fault free parts and products to attain high productivity. This is achieved by keeping the process in control, and by giving the authority to identify and adjust the defective products to workers.
- Just-in-time, i.e. providing every process with one part at a time, exactly when that part is needed
- Pull instead of push (scheduling of material)
- Multifunctional teams, which are groups of employees who are able to perform many different tasks. Two principles, decentralised responsibilities and integrated functions, are related to multifunctional teams. Decentralising responsibilities requires that each multifunctional team is given the responsibility of performing all the tasks along its part of the product flow, while the principle of integrated functions indicates that indirect functions are integrated into the teams, which increases the work content of these teams and reduces the number of support functions needed.
- Vertical information systems. The objective is to provide timely information continuously, directly in the production flow. This information is of both strategic (overall performance and intentions of the company) and operational (performance of the team in question) type.

Sickler (2004, pp. 5-6) argues that lean operations should be based on the following philosophies or principles:

- Customer satisfaction, which includes high quality, on-time delivery, customer designed delivery modes and extended services.
- Elimination of waste in every area of business including customer relations, product design, supplier networks, production processes, and company management. The goal is to use less human effort, less inventory, less time, less management, less control and less space to exceed customer expectations. The types of waste typically considered include: 1. overproduction, 2. waiting for the next processing step, 3. inventory or Work in Process (WIP), 4. unnecessary processing, 5. transportation, 6. unnecessary movement, 7. making defective products, and 8. underutilizing people(not taking advantage of their abilities)
- Know your tools. Sickler (2004, p. 10) identifies 15 basic tools that can be used in the transformation process and argues that the real power of these tools is only achieved when they are all used in conjunction with one another under the influence of the Lean philosophy.
- Respect of human dignity and contribution to the production process, which is related to empowering and valuing employees, and understanding that they are the most important asset of the company

Womack and Jones (1996) stress the importance of systemic and strategic view in implementing lean and state that successful implementation requires that the philosophy or the though process that ties the techniques together into a complete system is understood. They propose lean thinking, which consists of the following steps:

1 Specify value: Define value from the perspective of the final customer, expressing it in terms of a specific product, which meets the customer's needs at a specific price and at a specific time.
2 Identify the value stream, i.e. the set of all actions required to bring a specific product through the three critical management tasks of any business: the problem-solving task running from concept through design to production launch; the information management task running from order-taking through scheduling and delivery; and the physical transformation task of turning raw materials into finished goods. Create a current-state map of existing conditions by identifying waste - activities that add cost but no value from the customer's perspective. Then design a leaner future state of the value stream that eliminates the waste.
3 Flow: As wasteful steps are identified and eliminated, make the remaining steps in the value stream flow easily. The goal is to have the steps happen in tight sequence (ideally, in continuous flow), with little or no waiting
4 Pull: Let the customer pull products as needed, decreasing reliance on sales forecasts. Pull production means making what the customer wants, when they want it, instead of relying on inaccurate forecasts.
5 Pursue perfection: There is no end to the process of reducing effort, time, space, cost, and mistakes.

Frameworks of lean production system

Toyota Supplier Support Center (1998, cited Won et al. 2001) have presented the following figure of the Toyota Production System. The figure indicates that the objective of TPS is controlling or reducing costs through elimination of waste. According to Won et al. (2001), a prerequisite for this is a stable manufacturing system, which in the TPS model is achieved through standardised work, levelled and balanced production and kaizen (continuous improvement). Further, the TPS is based on Just-in-Time production and Jidoka, which is the practice of designing machines and processes to deliver perfect quality through rapid recognition and solution of problems.

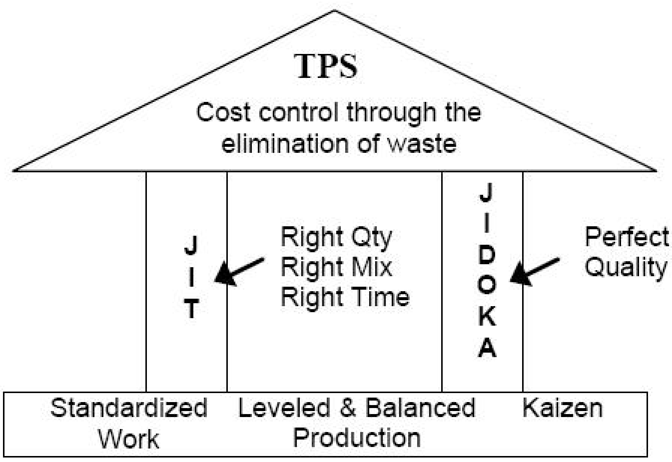

Figure 2. The TPS-framework (Won et al. 2001)

Spear and Bowen (1999) have conducted a four-year study of more than 40 plants, during which they tried to understand the success of Toyota. As a conclusion they emphasise firstly the importance of rigid specifications of activities, connections and production flows, which enable the flexible and adaptable operations that, and secondly the scientific methods that Toyota uses in solving problems and improving performance (Spear & Bowen 1999, p. 97). They also believe that the tacit knowledge that underlies the Toyota Production System can be captured in four basic rules, which guide the design, operation, and improvement of every activity, connection, and pathway for every product and service. The rules are:

- Rule 1: All work shall be highly specified as to content, sequence, timing, and outcome.
- Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.
- Rule 3: The pathway for every product and service must be simple and direct.
- Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

According to the authors, the rules require that activities, connections, and flow paths have built-in tests to signal problems automatically. It is the continual response to problems that makes this seemingly rigid system so flexible and adaptable to changing circumstances. (Spear & Bowen 1999, p. 98)

Monden (1998, cited Cochran et al. 2001) has developed a framework (figure 3) which presents numerous elements and improvement tools of the TPS, and also shows the relationships between these elements and the objectives of the system. The upward flow indicates the order in which the tools and elements should be implemented in order to achieve the high-level objectives, i.e. the lower-level elements are seen as prerequisites for higher-level elements and the ultimate objective of increasing profits (Cochran et al. 2001; Linck 2001, p. 38).

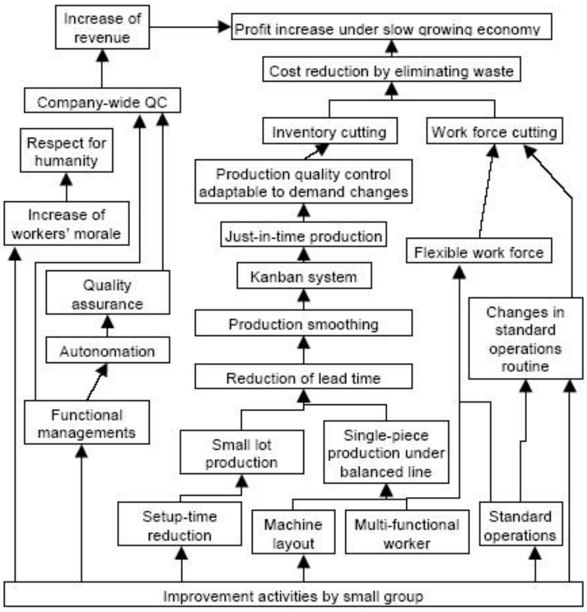

Figure 3. Implementation steps for Toyota Production System (Monden 1998, adapted from Linck 2001, p. 39)

Based on literature survey and plant visits, Sakakibara et al. (1993) have identified 16 core dimensions of JIT-production, which they regard identical to TPS. These dimensions have been grouped into 6 categories in a framework shown in the following picture. The upper part of the framework also presents the linkages between JIT and other functions and activities in an organisation, while the lower parts indicates that the six categories of JIT dimensions form a JIT manufacturing system, which is expected to improve manufacturing performance and result in competitive advantage.

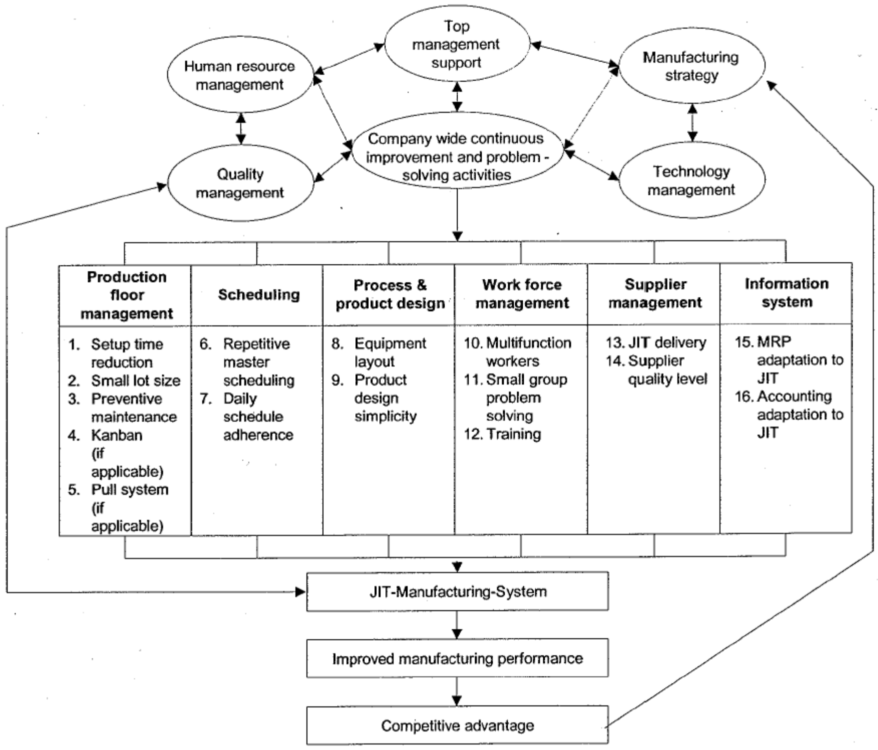

Figure 4. Core just-in-time manufacturing framework (Sakakibara et al. 1993, p. 183)

Suzuki (1999, cited Linck 2001) has formulated a framework (figure 5) that presents the tools and ideas needed to achieve JIT and Jidoka, the basic requirements for lean production and elimination of waste. The framework has been developed with help of Toyota Supplier Support Centre and it includes many similar elements than the framework proposed by the Toyota Supplier Support Centre (figure 2).

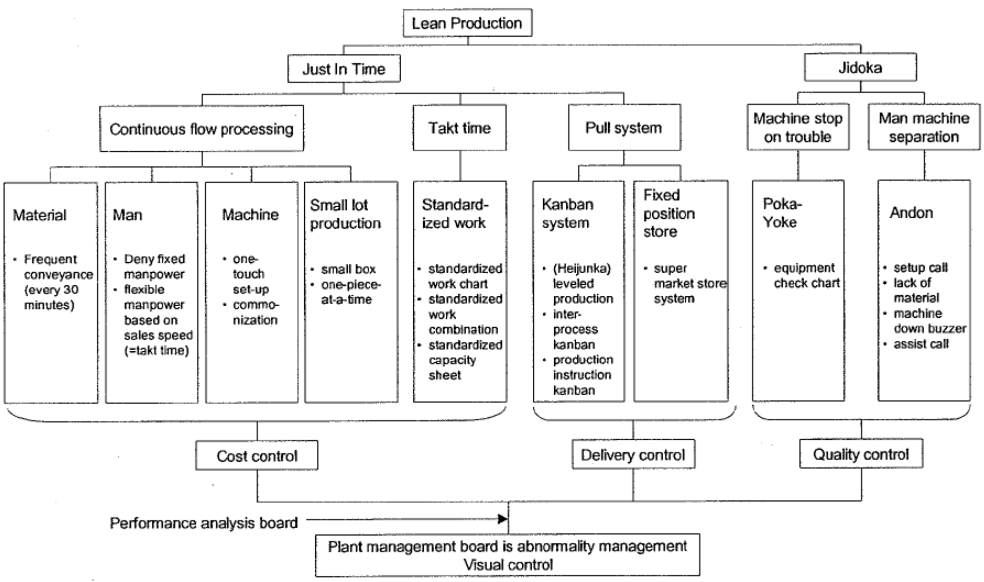

Figure 5. Lean production framework (Suzuki 1999, adapted from Linck 2001, p. 41)

Leagility and lean enterprise

In terms of implementing leagile supply chain, Mason-Jones (2000b, p. 59) argue that the use of agility and leanness and the engineering of supply chain can be identified by using market knowledge to position the decoupling point. Agility will be used downstream from the decoupling point and leanness upstream from the decoupling point.

When discussing the creation of lean enterprise, Womack and Jones (1994) state that the critical challenge for managers today is to synchronize the needs of the individual, the function, the company, and the value stream in a way that will yield the full benefits of the lean enterprise while actually increasing individual opportunities, functional strength, and the well-being of member companies. According to them, achieving this balance will require new management techniques, organizational forms, and principles of shared endeavour. The following solutions are proposed:

- Creating career paths that alternate between concentration on a specific value stream (a family of products) and dedicated, intense knowledge building within functions. This is required in order to attract and retain employees. (Womack & Jones 1994, p. 99)
- New roles for functions: 1) Schools, which systematically summarize current knowledge, search for new knowledge, and teach all this to their members, who then spend time on value-creating process teams and 2) developing guidelines, i.e. the best practices to be used by the companies of the value stream. (Womack & Jones 1994, p. 99-100)
- A Sharper Focus for Companies, which entails that each company in a value stream will tackle a narrower set of tasks that it can do well (Womack & Jones 1994, p. 101).

Definitions of Agile Manufacturing

Agile manufacturing has been defined as the new paradigm of manufacturing emerging in the 90s which incorporates high productivity and quality into the various products satisfying maximally the customers under the unexpected changing market environment (Kidd, 1994). Agile manufacturing adds “rapidity” or “agility” of time and “globalization” of space to the dimension of classical manufacturing. Manufacturers adopting this strategy response quickly and efficiently to the customer’s demands, produce continuously the products that satisfy maximally the customers, create a time gap to the losers, and increase market share.

Agile manufacturing can be defined as “an enterprise level manufacturing strategy of introducing new products into rapidly changing markets (Nagel and Dove, 1991) and “an organizational ability to thrive in a competitive environment characterized by continuous and sometimes unforeseen change” (Kidd, 1994).

Principles of Agile Manufacturing

Manufacturing companies that are agile competitors tend to exhibit these principles:

- Organize to Master change – An agile company is organized in a way that allows it to thrive on change and uncertainty (Goldman et al., 1995). In a company that is agile, the human and physical resources can be rapidly reconfigured to adapt to changing environment and market opportunities.
- Leverage the Impact of People and Information – In an agile company. Knowledge is valued, innovation is rewarded, authority is distributed to the appropriate level of the organization. Management provides the resources that personnel need. The organization is entrepreneurial in spirit. There is a "climate of mutual responsibility for joint success" (Goldman et al., 1995).
- Cooperate to enhance competitiveness – "Cooperation-internally and with other companies is an agile competitor's operational strategy of first choice" (Goldman et al., 1995). The objective is to bring products to market as rapidly as possible. The required resources and competencies are found and used, wherever they exist. This may involve partnering with other companies, possibly even competing companies, to form *virtual enterprises.*
- Enrich the Customer – "An agile company is perceived by its customers as enriching them in a significant way, not only itself" (Richards, 1996). The products of an agile company are perceived as solutions to customers' problems. Pricing of the product can be based on the value of the solution to the customer rather than on manufacturing cost.

As our definition and the list of four agility principles indicate, agile manufacturing involves more than just manufacturing. It involves the firm's organizational structure, it involves the way the firm treats it people, it involves partnerships with other organizations, and it involves relationships with customers. Instead of "agile manufacturing," it might be more appropriate to just call this new system of doing business "agility".

Agile Manufacturing in the 21st Century

Agile manufacturing requires resources that are beyond the reach of a single company. Sharing resources and technologies among companies becomes necessary. The competitive ability of an enterprise depends on its ability to establish proper relationships, and thus cooperation seems to be the key to possibly complementary relationships.

Agile manufacturing is attracting an increasing amount of attention from both the academic and industrial communities. Extensive programs are being conducted on relevant issues to propagate agile manufacturing concepts, to build agile enterprise prototypes, and eventually to realize an agile industry. The AMEF has sponsored several major conferences and has created at least 18 ongoing `focus groups' to explore further various aspects of agility and the infrastructure needed to support them. Considering the relevance of agile manufacturing we believe that new fruitful opportunities can be identified (Gunasekaran, 1998).

Enablers of Agile Manufacturing

The key enablers of agile manufacturing (Montgomery and Levine, 1996) include: (i) virtual enterprise formation tools/metrics; (ii) physically distributed manufacturing architecture and teams; (iii) rapid partnership formation tools/metrics; (iv) concurrent engineering; (v) integrated product/production/business information system; (vi) rapid prototyping; and (vii) electronic commerce.

Agility has been expressed in different ways. In one way it has been introduced as a total introduction of business components (Kidd, 1994). In another way it has been introduced as flexibility of manufacturing, people and organization (Hai et al., 2003). Moreover, expressions such as: concurrency, adaptability, use of information systems, technologies and diverse combinations are used in defining agile manufacturing (Kidd, 1994).

Until now, proposals for ways to become agile and characteristics defined for an agile manufacturer have been more or less experienced in an Utopian way (Cho and Jung, 1996). Although in the other hand, no business has been reported to possess all the required specifications of agility are making ground for the development of realistic and applicable models to deliver the concept of agility in practice.

Agile Manufacturing Paradigms

The manufacturing paradigm is changing from Mass Production to Agile Manufacturing. Because of the highly competitive global market the mass markets are fragmenting into niche markets. Cooperation of companies have become a necessity even between the direct competitors. Due to the increasing customer expectations on low volume, high quality and custom made products the Industry is facing a shift toward Agile Manufacturing (Gunasekaran and Yusuf, 2002).

Illustration of Agile Manufacturing Paradigm

In this section an illustration on the supporting parameters for Agile Manufacturing are reviewed. These supporting parameters include the Market Focus, Customers demand etc.

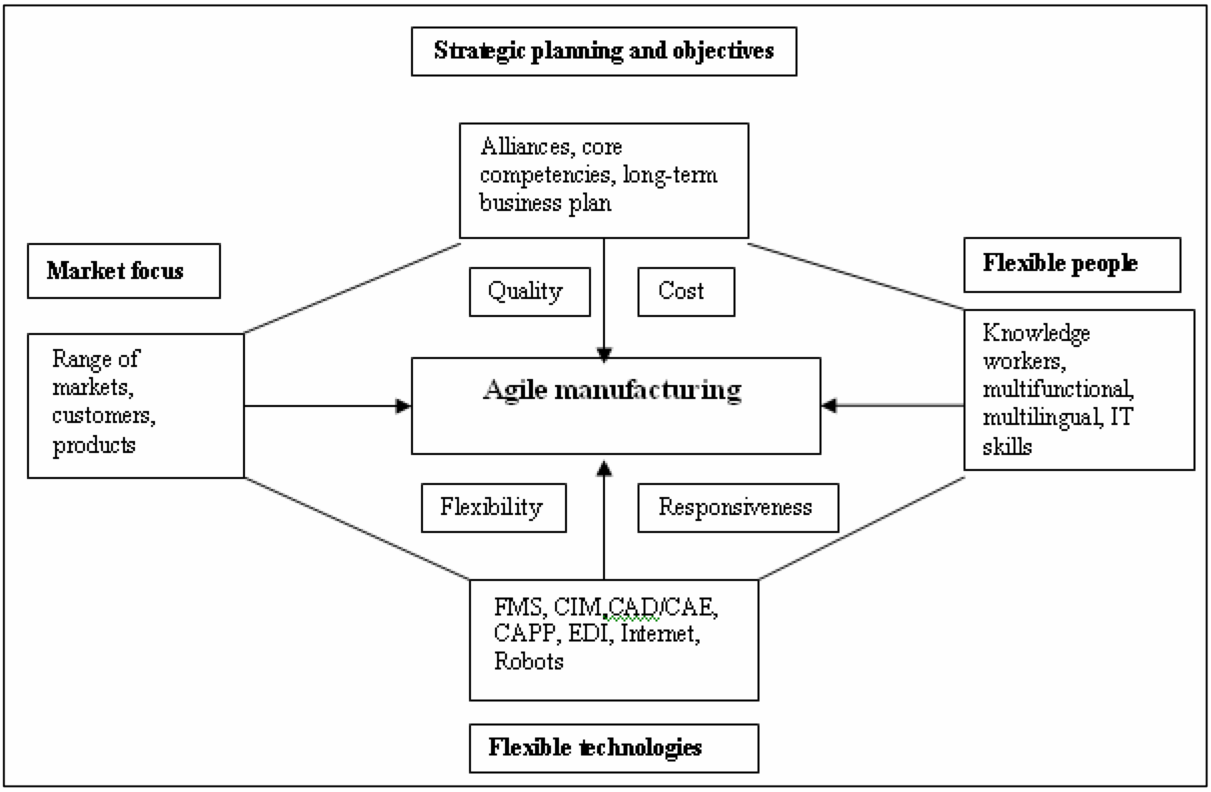

Figure 6: Agile Manufacturing Paradigm (Sanchez and Nagi, 2001)

Flexible Technologies: - Since agile manufacturing aims at a variety of products, the manufacturing facility should be flexible. Introduction of flexible manufacturing system, automated machines, Robots for material handling, use of CAD/CAM software packages will result in a automated manufacturing system.

Flexible people: - This term describe the skills a particular person can have. The people working in a facility should be multi-skilled.

Market focus: - There should be a thorough market research done before implementing any new system. In today's world, a product is designed according to the customer's requirement. Also customer needs a variety of products. Thus the manufacturing system should be capable of providing what the customer demands in a timely manner.

Strategic Planning and Objectives: - The organization should have long term business plans in order to target the market at the right time. Thus in order to survive in the competitive market, it should have well defined strategies. Many organizations introduce a product/service as a collaborative effort (alliance) which is a type of business strategy.

Market Forces and Agility:

A number of forces can be stated which are driving the evolution of agile manufacturing in business. **Increasing Competition**: Presence of several organizations producing similar type or product or rendering same service increases the competition automatically. Other factors like decrease in cost of information, communication technologies, pressure to reduce time-to-market; short product life cycle can also intensify competition.

Fragmentation of mass market:

The signs towards market fragmentation includes emergence of niche markets, rapid model changes, declining barriers to market entry from global competition and introduction of virtual enterprise.

Cooperative business relationships:

The cooperation can take many forms like inter-enterprise cooperation, increase in amount of out-sourced components, global sourcing, improvement in labor-management relationships.

Changes in Customer's expectations:

Customers are becoming more sophisticated and individualistic in the product selection. The purchased product should function as per requirements throughout the products life, high quality at low cost are some of the customers' demands. Thus quality has no longer remained the basis of competition now.

Increasing societal pressures:

Modern companies are expected to be responsive towards social issues like workforce training, environmental issues and civil rights issues.

Agile manufacturing strategies and technologies

Agile manufacturing comprises of several strategies and technologies. These are discussed in detail as follows (Cheng et al. 1998):

Strategic planning

Strategic planning is done in order to improve the performance of the existing system related to all manufacturing areas. To make the manufacturing system agile, strategies like virtual manufacturing, rapid partnership formation, and temporary alliance are required. Suitable business and operation strategies in coordination with excellent manufacturing capability will provide agility. As the complexity in the production and marketing increases, new performance indicators should be defined. Lean operations increases the speed and also flexibility is required to become an agile enterprise.

Responsibility Based Manufacturing (RBM) was a new architecture that was introduced in agile manufacturing paradigm. RBM allows adjustments in process and product variety without altering the system configuration. The major issues in developing agile manufacturing environment are the utilization of resources in order to meet the challenges of the market variability, technological advancements. Also importance should be given to logistics and supply chain management.

The agile concept can be applied at any levels in manufacturing or specifically to a activity that is from product development to distribution. For an agile supply chain, the Top Management's involvement is a must. This results in effective interaction between the suppliers and improves product delivery and services.

Product Design

The agile manufacturing system should be capable of producing a variety of products at low price and in a short period of time. The product development cycles can be improved by using techniques such as CAD, Computer Aided Engineering (CAE), Design for Manufacturing and Assembly. Agile manufacturing requires coordination and concurrency between representatives of different teams such as design, quality assurance, marketing, purchase, production.

Agile manufacturing requires rapid product design system with an objective of switching over to different or new products as quickly as possible. Simultaneously, the non value adding activities should be reduced for the timely delivery of the product into the market. A new concept of Virtual Design Environment (VDE) has been introduced by Subbu et al in 1998 using the CORBA distributed programming tool. It is to support Design- Manufacturing- supplier- Planning decisions in a distributed environment.

Virtual Enterprise

A virtual enterprise is the integration of complementary core competencies distributed among a number of carefully chosen but real organizations all with similar supply chains focusing on speed to market, cost reduction and quality (Abair 1995). Temporary partnerships based on core competences of firms helps to increase the flexibility and responsiveness.

Virtual Enterprise will enhance all the levels of decision and control in the organization. Virtual Enterprise are temporary environment which can be easily altered depending upon the product design, process design, operations and other activities. Apart from other activities in manufacturing, the supply chain management requires a different framework, strategies and measurement criteria.

Automation and Information Technology

Agile manufacturing requires an intelligent sensing and decision making system capable of executing tasks which are done by humans, for example visual inspection. Integration of systems based on automation for different activities is complicated because of the virtual nature. Thus an intelligent Concurrent Engineering design support system can provide a rapid evaluation and response to any changes.

These changes could be related to product design, process or both. Talking about automation, agility can be brought by using Automated Guided Vehicles (AGV's), NC machines, CAD/CAM tools, Internet, Electronic Data Interchange (EDI), E-Commerce which are properly integrated and shows required response to each other. Information technology integrates the physically distributed manufacturing firms. MRP-II, ERP are most widely used.

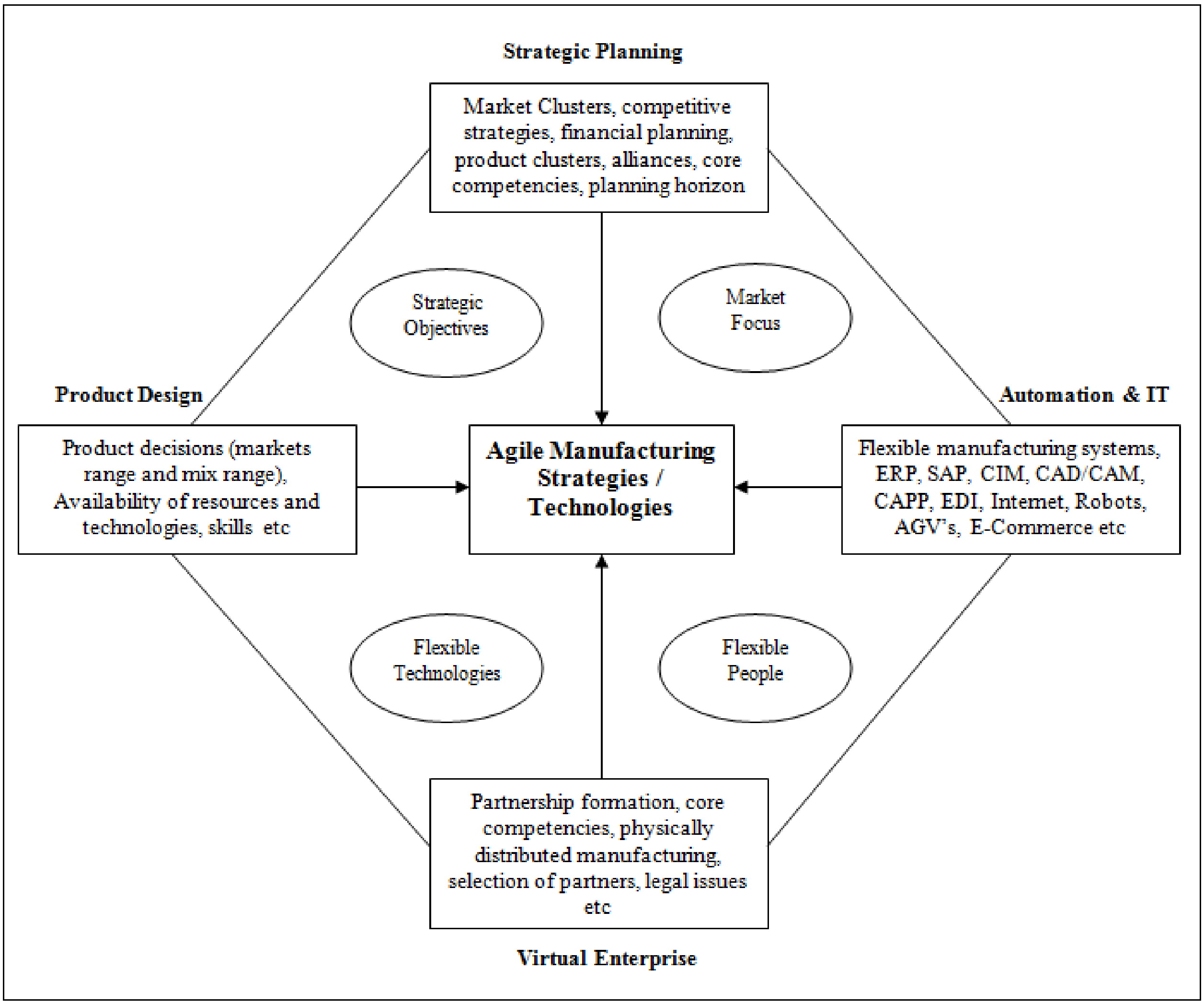

Figure 7: Agile Manufacturing Strategies/Techniques (Montgomery et al., 1996)

Definitions of Sustainable Manufacturing

Sustainability" means the capacity to endure. In ecology, the word "sustainability" describes how biological systems remain diverse and productive over time. Long-lived and healthy wetlands and forests are examples of sustainable biological systems. For humans, sustainability is the potential for long-term maintenance of well-being, which has environmental, economic, and social dimensions. In a manufacturing context, sustainability is the ability of a company to provide value to its shareholders, community and the planet.

Although there is no universally accepted definition of Sustainable Manufacturing, numerous efforts have been made to define Sustainable Manufacturing. Sustainable Manufacturing is defined by the United Nations Brundtland Commission as the one that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). According to the USA department of Commerce, Sustainable Manufacturing is defined as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound."

OECD Analysis on Sustainable Manufacturing

In recent decades, expanding economic activity has been accompanied by growing concerns about climate change, energy security and scarcity of natural resources. While industries are showing greater interest in sustainable production and are undertaking a number of corporate social responsibility (CSR) initiatives, progress falls far short of meeting these pressing challenges. Moreover, improvements in efficiency in some regions have often been offset by increasing consumption in other regions, while efficiency gains in some areas are outpaced by scale effects.

Without new policy action, recent OECD analysis suggests that global greenhouse gas emissions are likely to increase by 70% by 2050. Provided that governments send a clear policy signal now about their medium and long-term climate change objectives, the cost of climate policy measures could be kept quite low in the next few years. Raising efficiency in resource and energy use and engaging in a broad range of innovations to improve environmental performance will also help to create new industries and jobs in coming years.

The current economic crisis and negotiations to tackle climate change should thus be seen as an opportunity to shift to a greener economy. Incremental improvement is not enough, however. Industry must be restructured and existing and breakthrough technologies must be more innovatively applied to realize green growth. Short-term relief packages deployed today can stimulate investments in technologies and infrastructures that help innovation and enable changes in the way we produce and consume goods and services in the future. Innovation can result in new technological and systemic solutions to environmental challenges and can efficiently support the development and diffusion of eco□innovation.

Sustainable Manufacturing and Eco‑innovation: Towards a Green Economy:

Innovation has long been seen as central to economic performance and social welfare; it is increasingly recognized as a significant driver of economic growth. More recently, industry leaders and policy makers have also looked at innovation as the key to making radical improvements in corporate environmental practices and performance

The OECD defines innovation in its Policy Brief 2009 June issue as “the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations”. Eco-innovation is generally the same as other types of innovation but with two important distinctions:

- Eco-innovation represents innovation that results in a reduction of environmental impact, no matter whether that effect is intended or not.
- The scope of eco-innovation may go beyond the conventional organizational boundaries of the innovating organization and involve broader social arrangements that trigger changes in existing socio-cultural norms and institutional structures.

Sustainable Manufacturing Innovation and Practices by Industries:

Industries have traditionally addressed pollution concerns at the point of discharge. Since this end-of-pipe approach is often costly and ineffective, industry has increasingly adopted cleaner production by reducing the amount of energy and materials used in the production process. Many firms are now considering the environmental impact throughout the product’s lifecycle and are integrating environmental strategies and practices into their own management systems.

Some pioneers have been working to establish a closed-loop production system that eliminates final disposal by recovering wastes and turning them into new resources for production. Eco-innovation helps to make possible this kind of evolution in industry practices. While more integrated practices, such as closed-loop production, could potentially yield substantial environmental improvements, they can only be realized by combining a wide range of innovation targets and mechanisms, and both technological and non-technological changes.

A study of eco-innovation from three industry sectors suggests that the primary focus of current eco-innovations tends to rest on technological developments and advancements. The automotive and transport industry has taken several steps to reduce CO_2 emissions and other environmental impacts, notably those associated with fossil-fuel combustion.

Thirty five steel manufacturing companies which manufacture advanced high strength steel for cars formed the Ultra-Light Steel Auto Body (ULSAB) initiative in 1994, in partnership with an automotive engineering company. Since cars built with advanced high-strength steel are lighter, their power train can be downsized, thus substantially improving the vehicles fuel economy and reducing CO2 emissions over their lifetime.

Eco-innovations in the automobile industry have been realized largely through technological advancements, typically in the form of product or process modification and re-design, such as more efficient fuel-injection technologies, better power management systems, energy-saving tyres and optimization of painting processes.

The iron and steel industry has made significant progress in increasing its environmental performance through a number of energy-saving modifications and re-designs of various production processes. New ways of working within the industry have made many of these technological advances in products and processes possible. For example, an international collaboration between vehicle designers and steel makers resulted in the development of advanced high-strength steel to manufacture lighter and more energy-efficient automobiles.

The electronics industry has so far been mostly concerned with its products energy consumption. With consumer demand for electronic equipment exploding, companies are also seeking more efficient ways to dispose of their products. Most eco-innovations in this industry have focused on technological advancements in the form of product or process modification and re-design. These, in turn, build upon a number of innovative organizational and institutional arrangements. A notable example is IBM’s use of large-scale Internet discussion groups to harness innovative ideas circulating among thousands of people.

Approaches in Sustainable Manufacturing:

From the 1980s, activities in sustainable manufacturing started to focus on waste reduction in production, so-called cleaner production. The activities were extended to the reduction of resources and energy use in production. After this, the paradigm for sustainable manufacturing has been changed from production-oriented to product–oriented one. The changed paradigm is realized by the Integrated Product Policy (IPP). The product-oriented approaches are, on the one hand, activities for reduction of resources and energy in a product. On the other hand, there are activities for reduction of toxic materials, and development and use of renewable materials.

Until now, the scientific approaches have neglected to enhance sustainability in the use phase and have also focused on the design for environmental and material level recycling. However, sustainable manufacturing for the next generation should focus on enhancing use-productivity in the total product life cycle. For enhancing use-productivity, there are the three strategies which are illustrated by the figure below.

- Implementation of Innovative Technologies is a strategy focusing on the evaluation and implementation of feasible and innovative technologies for resource-saving applications.
- Improving the Use-Intensity is a strategy to improve use-productivity by increasing the utilisation ratio of a product. This strategy intends to maximise productivity per resource input.
- Extension of Product Life Span is a strategy focusing on extending the time between cradle and grave of a product by expanding the use phase and realising multiple use phases. The resource consumption for production and disposal of products shall be reduced with this strategy.

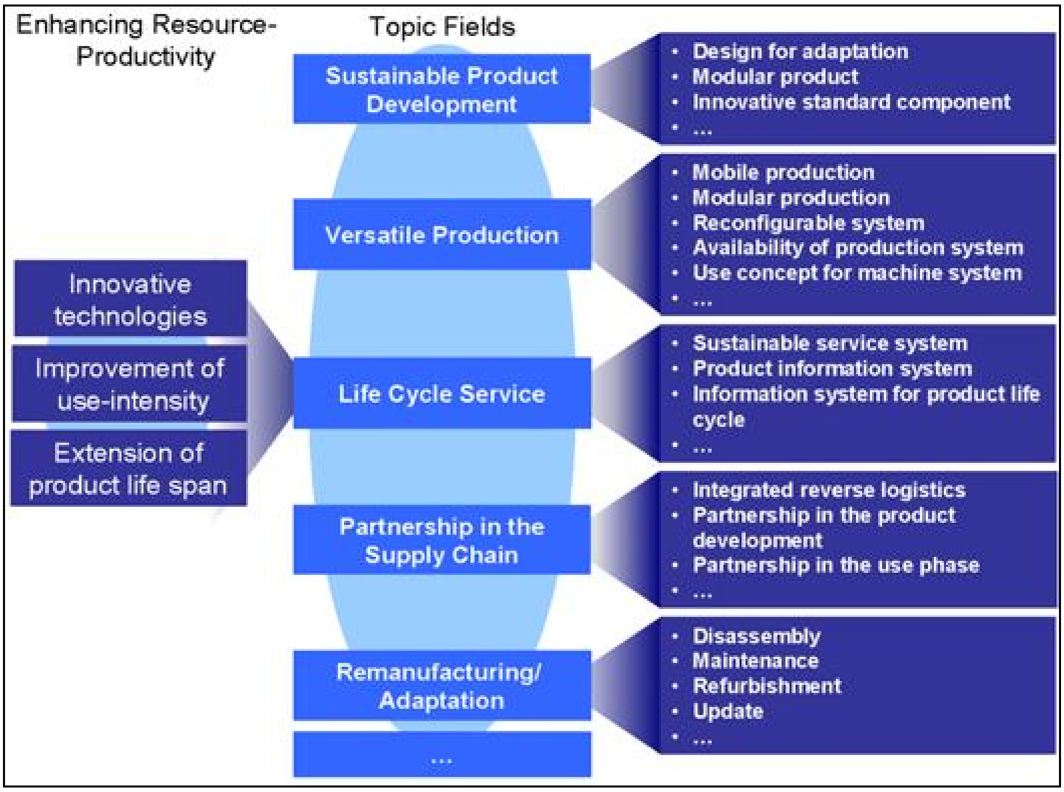

Figure 8: Framework for Sustainable Manufacturing (Seliger et al., 2008)

Extension of Product Life Span:

Extension of the product life span can be achieved, on the one hand, by expanding the use phase and, on the other hand, by the realization of multiple use phases. Maintenance and modification are means of expanding the use phase of a product. A balanced strategy of preventive maintenance preserves or increases the residual value of a product.

Modification is the adaptation of a product during the use phase due to changed functional requirements. Kinds of adaptation are up- and downgrading, enlargement and reduction as well as rearrangement and modernization. Modification and adaptation require disassembly and reassembly processes (Müller, 2001). Additional processes are cleaning, testing, component supply and removal.

Multiple use phases are realized by remanufacturing and adaptation. Nasr defines remanufacturing as reviving a product to a like-new condition in terms of performance and durability by disassembling, cleaning, inspecting, repairing, replacing the components of a product (Nasr, 2004). Adaptation processes are applied to react on changed functional requirements of the next use phase in the respective market. Requirements to products for this strategy are modularity, integrability, customization, convertibility, and diagnosability supporting efficient processes of preventive maintenance and modification as well as remanufacturing and adaptation.

Since manufacturing is the core operation in a product’s supply chain, when considering physical products, designing the system and promoting sustainability in its operations must center on a sustainable manufacturing approach by focusing on a broader, innovation-based 6R methodology to not only reduce, reuse and recycle but also to recover, redesign, and remanufacture the products over multiple life-cycles (Joshi et al., 2006).

In the 6R methodology, reduce mainly focuses on the first three stages of the product life-cycle and refers to the reduced use of resources in pre-manufacturing, reduced use of energy and materials during manufacturing and the reduction of waste during the use stage (WCED, 1987). On the other hand, reuse refers to the reuse of the product or its components, after its first life-cycle, for subsequent life-cycles to reduce the usage of new raw materials to produce such products and components. Recycle involves the process of converting material that would otherwise be considered waste into new materials or products (WCED, 1987).

The process of collecting products at the end of the use stage, disassembling, sorting and cleaning for utilization in subsequent life-cycles of the product (Joshi et al., 2006) is referred to as recover. The act of redesigning products to simplify future post-use processes through the application of techniques, such as Design for Environment (DfE), to make the product more sustainable is referred to as redesign while remanufacture involves the re-processing of already used products for restoration to their original state or a like-new form through the reuse of as many parts as possible without loss of functionality (Joshi et al., 2006).

Combining Lean, Agile and Sustainable Paradigms

When the aspects of Lean, Agile, and Sustainable Manufacturing are considered as one system, Lean emphasized the stability of a system and standardization of manufacturing activities while agility adds the needed capability to change to new situations, therefore focusing more on the collaboration in a supply network. These two have their main focus on economic and social issues while sustainability adds the viewpoints of energy and environmentally friendly manufacturing. In principle, sustainability includes and presupposes economic viability and including competitiveness would not be necessary. However, combining competitiveness and sustainability aims to emphasize that, e.g. environmental aspects, should not be regarded as additional costs, but as a source of competitive advantage and new business opportunities (Koho et al., 2010).

Since a lot of similarities exist between Lean and Agile Manufacturing Systems they are often subjected to comparisons. There is a common misinterpretation that Agile Manufacturing represents an evolutionary next phase of Lean. But in reality, the two systems do not compete and in fact agility complements Lean. The principles and the function of the production paradigms are compared in Table 1. Similarly, Table 2 recognizes wastes identified by Lean and its environmental impacts.

Table1: Comparison of Lean Production and Agile Manufacturing Attributes (Mikell, 2001)

	Lean Production	**Agile Manufacturing**
1	Minimize Waste	Enrich the Customer
2	Perfect first time quality	Cooperate to enhance competitiveness
3	Flexible Production Lines	Organize to master change
4	Continuous Improvement	Leverage the impact of people and information.
5	Emphasis more on Technical and Operational Issues	Emphasis on Organizational and People Issues
6	Process Focused	Boundary Focused
7	Minimize Change	Embrace Change

Table2: Wastes Identified by Lean and its Environmental Impacts

Waste Type	**Examples**	**Environmental Impacts**
Defects	Scrap, rework, replacement production, inspection	• Raw materials consumed in making defective products. • Defective components require recycling or disposal. • More space required for rework and repair, increasing energy use for heating cooling and lighting
Waiting	Stock-outs, lot processing delays, equipment downtime, capacity bottlenecks.	• Potential material spoilage or component damage causing waste. • Wasted energy from heating, cooling and lighting during production downtime.
Overproduction	Manufacturing items for which there are no orders.	• Raw materials consumed in manufacturing un needed products. • Extra products may spoil or become obsolete requiring disposal.
Movement	Human motions that are unnecessary or straining, carrying work in process (WIP) long distances, transport.	• More energy use for transport • Emission from transport • More space required for WIP movement, increasing lighting, heating, and cooling demand and energy consumption. • More packaging required to protect components during movement.
Inventory	Excess raw material, WIP or finished goods.	• More packaging to store work in process • Waste from deterioration or damage to stored WIP. • More materials needed to replace damaged WIP. • More energy used to heat, cool and light inventory space.
Complexity	More parts, process steps, or time than necessary to meet customer needs.	• More parts and raw materials consumed per unit of production. • Unnecessary processing increases wastes, energy use and emissions.
Unused Creativity	Lost time, ideas, skills, improvements, and suggestions from employees.	• Fewer suggestions of P2 and waste minimization opportunities.

Lean, Agile, and Sustainable factors

Changeability is widely discussed in (Wiendahl et al., 2007) from several different aspects and is generally defined as: characteristics to accomplish early and foresighted adjustments of the factory's structures and processes on all levels to change impulses economically. Similarly, changeability herein is used as a general term to explain the ability of a manufacturing system to change or to adapt to meet the requirements of the labile markets.

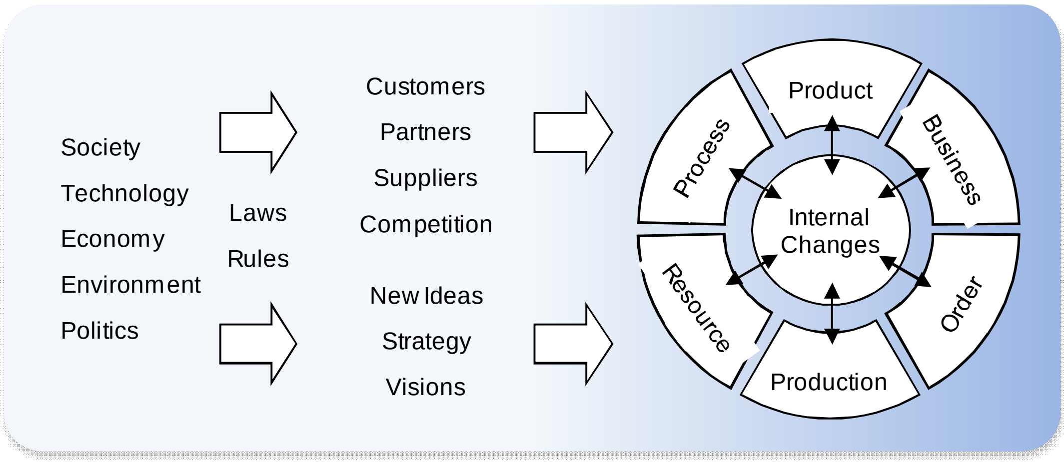

Figure 9. Examples of external and internal changes a manufacturing system faces.

Figure 9 presents several typical sources of change that manufacturing systems face when they operate in a constantly changing environment. The changes can be external or internal, direct or indirect (Wiendahl and Heger, 2005). Typical external and indirect sources for change are in the context of STEEP (society, technology, economy, environment, and politics) (Tuokko, 2009). Laws and different rules are examples of external and direct sources for change. These sources can be mandatory or voluntary. Mandatory sources force the manufacturing system to adapt to the changes. For those changes that are voluntary, it depends on the strategy and decisions within the manufacturing system how to react to the situation as the decisions will have an impact on the competence of the manufacturing system.

Competition, customers, partners, and suppliers are examples of external and direct sources for change from the viewpoint of a manufacturing system. They differ from the other external and direct sources in their nature, as they are similar entities communicating in the same environment as the manufacturing system itself. Similarly, new ideas, strategy, and future visions can derive from the manufacturing system itself or influenced from the context.

The external changes will cause internal changes that will change the system. The changes can affect the system entities as well as their related domains. A change within a system will almost always cause a chain of change events until the system has adapted to the new situation.

The factors in a context of a proposed structure of manufacturing systems

The factors are viewed against a proposed structure of manufacturing systems. It consists of manufacturing entities as well as their related domains. An entity is something that has a distinct existence and can be differentiated from other entities while a domain is an area in which two or more entities are collaborating.

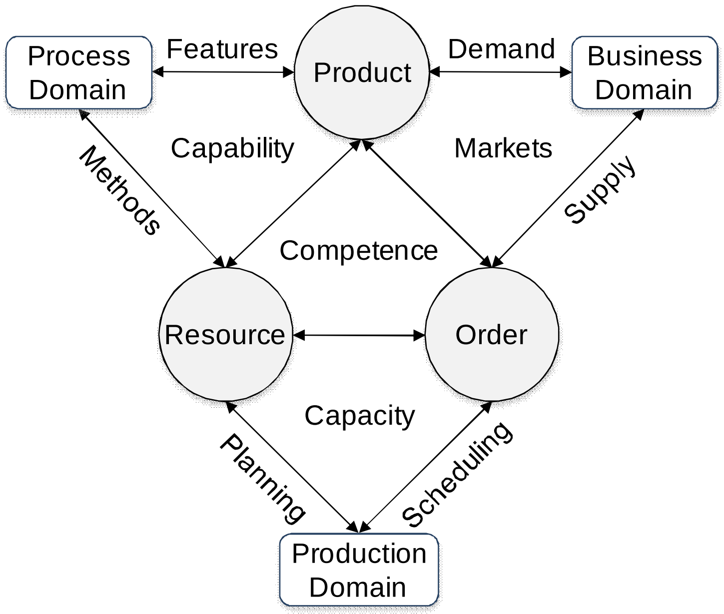

Figure 10. Structure of manufacturing systems (Nylund and Andersson, 2011).

Figure 10 shows a general presentation of manufacturing entities and their connecting domains. Brief descriptions of those are:

- Products represent what is offered to customers. The characteristics of the products specify the requirements for the manufacturing system, i.e. what the system should be able to do.
- Resources embody what is available to manufacture the products. The capabilities of the resources determine what can be manufactured. Resources include machines, devices, and tools as well as human resources.
- Orders represent instances of products that are ordered by customers. They define the volume and variation requirements of the products ordered, as well as the capacity and scalability requirements for the manufacturing system.
- The process domain represents the capabilities that are needed to manufacture the products. It connects the development activities of products and resources.
- The production domain defines the capacity and scalability to manufacture changing volumes and variations in customer orders. It handles the material and information flow of the manufacturing system.
- The business domain is responsible for markets, i.e. for the right products being available for the customers to gain enough orders.

Table 3 collects together several aspects of Lean, Agile, and Sustainable divided into the six categories of the proposed structure of manufacturing systems. The table is constructed in the way that Lean and agility concerns productivity and economic issues and the social and environmental aspects are mostly included as factors of Sustainability.

Table 3. Examples of aspects having impacts on manufacturing systems

<table>
<tr><th></th><th>Lean</th><th>Agile</th><th>Sustainable</th></tr>
<tr><td rowspan="2">Product</td><td colspan="2">• Product platforms
• Modularity
• Configuration
• High mix, low volume
• Industrial product-service systems, maintenance, and after sales</td><td rowspan="2">• Lifecycle view on environmental impacts
• Modularity for post-use, reusable and recyclable modules
• Use of renewable and non-toxic materials
• Increasing product reliability and prolonging life of products</td></tr>
<tr><td>• Product families
• Standardization
• Near net-shape blank parts
• Small and light work pieces</td><td>• Custom made, unique products
• Part commonality
• Material flexibility</td></tr>
<tr><td rowspan="2">Process</td><td colspan="2">• Process capability, first time right
• Waste elimination
• Performance predictability
• Process ownership</td><td rowspan="2">• Energy harvesting
• Reducing use of energy and materials
• Reducing emissions and waste
• Additive manufacturing
• Ergonomics of operations
• Eco-efficient mfg methods</td></tr>
<tr><td>• Stable manufacturing processes
• Standard manufacturing processes
• Continuous improvement
• Zero defect processes</td><td>• Predictable manufacturing processes
• Flexible and configurable processes</td></tr>
<tr><td>Resource (machines, devices)</td><td>• Simple ”one-purpose” machines
• Automation with human touch (autonomation)
• Single minute exchange of die</td><td>• Flexible and configurable manufacturing resources
• Multipurpose machine</td><td>• Eco-efficient machines
• Reusability, recyclability, upgradability, and retirement of resources
•</td></tr>
<tr><td>Resource (people)</td><td>• Value stream based teamwork and learning organization
• Multi-skilled workers with job rotation
• Systematic problem solving</td><td>• Multi-skilled workers
• Adaptive organization
• Adaptive problem solving</td><td>• Safety and health issues
• Environmental awareness
• Well educated and committed people on eco-issues</td></tr>
<tr><td>Production</td><td>• Just-In-Time pull production
• Cell production
• Visual control
• Single-piece or small batch continuous flow
• Work Standardization
• Economies of repetitiveness</td><td>• Configurable and changeable structures of production systems and supply network
• Supply network transparency and supplier reliability
• Plans for alternative solutions, e.g. routing flexibility
• Late point differentiation of products</td><td>• Eliminating emissions and waste
• Use less material and energy
• Cleaner manufacturing, green manufacturing
• Heating and cooling
• Lightning and ventilation
• Zero landfill
• Reusable packing material</td></tr>
<tr><td>Order</td><td>• Levelling of orders
• Defined product families
• Order penetration point, Pacemaker
• Repetitive batches with appropriate annual volume</td><td>• High mix – Low volume
• Mass Customization
• Late order penetration point
• Order configurability</td><td>• Reverse logistics
• Closed-loop lifecycle
• Product take-back and recovery</td></tr>
<tr><td>Business</td><td>• Lead time reduction through elimination of waste (muda)
• Make to stock (MTS) or assemble to order (ATO)
• Cost management
• Transparent long-term partnership
• Supply management
• Internal customer relationship
• Long-time relationship with suppliers and customers</td><td>• Customized products with high-pricing potential
• Make to stock (MTS) or engineer to order (ETO)
• Collaborative network (focus on connecting the core competences)
• Known capabilities
• Changing market
• Customer relationship</td><td>• Sustainability strategy and management
• Green labelling and branding
• Globally local manufacturing
• New business models and opportunities Sustainability issues as services provided by third parties</td></tr>
</table>

Viewpoints for Manufacturing Performance Measurement

Figure 11 presents an overview of manufacturing performance measurement and metrics. The left side of the figure represents the internal view of the performance measurement. The right side, being the external view, shows the performance metrics. The performance measurement is divided into manufacturing process monitoring, manufacturing flow efficiency, and competence of the company. Similarly, a manufacturing company can be divided into fractal levels of manufacturing stage, factory, and enterprise.

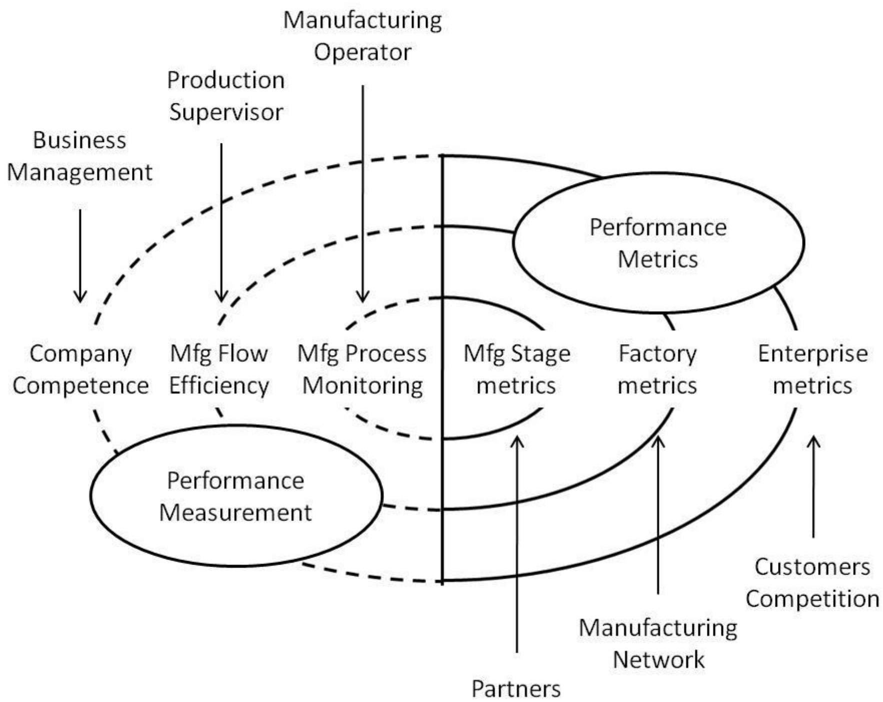

Figure 11. Internal and external views of performance measurement and metrics

Different people in a manufacturing company are responsible for different areas of manufacturing and therefore are interested in different performance metrics measured. A manufacturing unit operator, being responsible for keeping the manufacturing process running, needs metrics to define that the behaviour and characteristics of the process are within accepted value limits. A production supervisor, as responsible for a factory level manufacturing activities, is more interested in the metrics concerning on the efficient and timely flow on material and information. In business management the focus is on keeping the competence of a company on a desired level i.e. the whole company follows and fulfils the competitive and sustainable goals and objectives of the selected business strategy.

Typical for the present-day industrial activities are the networked cross company collaboration activities. Therefore the performance metrics interests different players in industrial networks. The most detailed collaboration exists within partners meaning that they may be interested in the internal metrics of a manufacturing stage. The collaboration can exist both in a supply chain in e.g. defining material properties and product features as well as in between product and manufacturing development. In a manufacturing network the factory metrics are more important as the capabilities to manufacture products can be distributed into multiple companies and the factory metrics can aid when selecting the potential partners and suppliers. Enterprise metrics interest both the customer and competitors. The customers are interested to find the best possible product and service provider while the competitors are eager to find how they can differentiate themselves from their competition is a positive way.

The metrics discussed in Table 4 are focused on what can be measured from the intelligent manufacturing environment. Therefore several aspects of are not included in the discussion. Typical issues left out from the analysis of this report are operational and accountable or investment costs of the operational system and surrounding area, and human resource costs.

Table 4. Key indicators for performance objectives, adapted from (Mani et al., 2008; Shahbazpour and Seidel, 2006; Lanz et al., 2010)

Performance metric	**Includes**	**Is measured by**
Cost	Production and distribution costs including the personnel costs	Cost per defined time
Production Load	Volume and variation of the ordered product mix	Production rate and speed
Quality	Products as well as manufacturing systems and processes	Capability to produce approved parts
Resource utilization	Optimal resource utilization	Idle, set-up, and operational times, that are directly linked to the resource entities
Time related metrics	Production efficiency	Throughput- and tact-time as well as busy, wait, and idle times that are related to each part, product, or patch
Energy consumption	Production system energy utilization	Power or energy per defined time
Material consumption	Amount of material used	Difference between ordered material and produced waste
Waste	Scrap material, pollution and emissions	Material consumption, and energy consumption of the system based on the energy source

Performance factors in relation with Sustainability

As cited by multiple sources, see, for example: (Jovane, 2009; Mani et al., 2008; 2006; Lanz et al., 2010), the sustainability is defined as 'economic development that meets the needs of the present generation without compromising the ability of future generation to meet their own needs'. This is often translated and generalized as reducing waste and emissions, conserving energy, conserving natural resources and reducing business impact on ecosystems. By taking this definition in to the field of manufacturing, the sustainability can be seen as conflicting issue with manufacturing objectives. These conflicts are often referred as trade-offs.

Sustainability as a manufacturing objective can have a trade-off relationship with other competitive objectives when and where the relationship between sustainability and systems parameters such as resources, energy, material, waste, and emissions is in contradiction to the relationship between other objectives and parameters (Shahbazpour and Seidel, 2006). Camahan and Thurston (2008) illustrated the trade-offs by stating that the material choice and manufacturing process settings that result best quality of the product lead to an increase in air pollution and manufacturing cost, and the effort of reducing material costs and solid waste material also conflict with the goals to reduce processing times and carbon emission levels. Based on (Lanz et al., 2010) the impact of reducing the energy consumption of machining processes is relatively insignificant. They question arises: what is the sustainable manufacturing and how to measure it?

As each of the roles (instances) has different interest towards manufacturing performance factors and sustainability goals the conflicts between desired objectives and goals will eventually manifest. For achieving the sustainable manufacturing measuring the performance metrics is not enough, it is needed to know where the changes affect and how the measured results are formed. In broader sense, the sustainable manufacturing is to understand the full system, its behaviour and objectives.

Utilizing the factors in Factory Simulation

The purpose of factory simulation is to understand the characteristics and behaviour of a real factory, and to analyse different scenarios in a changing environment. This kind of simulation is usually built using tools and principles of DES. DES is widely accepted as a valuable research method for predicting the performance of factories and manufacturing systems, but it is applied in a small fraction of cases, i.e. in those where it can bring significant value (Pegden, 2005). For factory simulation, the factors are required to be realised as more formal input parameters. The parameters usually have two or more predefined values or a range of values to select from, limited by the practical conditions that can be realised on a real factory floor.

Production

The division of the input parameters also follows the ideas of the proposed structure of manufacturing systems. The production domain equals the factory floor and therefore, presents the simulation model to be constructed. Other portions define the structure of the factory floor, how the production is controlled, and more generally how the production activities are managed based on goals, requirements, and constraints.

The factors of design, development, and operation of a factory derive from the business domain i.e. the strategic issues of a company affecting the factory floor operations. Orders present what is fed into a simulation model. They are instances of products that have been modelled. The orders flow thru the simulation model between resources forming a chain of processes that are required to transform the orders to finished products.

Products, Processes, and Resources

Processes link products and resources i.e. what manufacturing resources are capable of performing the requirements of the products. For factory simulation, a typical manufacturing process has the following input information.

- Process requirements i.e. what products, workers, and aiding resources are needed to start a process on the main resource
- Dividing the process into sub processes if required. For example, a machining process that consists of sub-processes of setup, load, machining, and unload.
- Mean and variation of process times
- Learning curve that typically decrease both the mean and deviation of the duration of a process
- Use of energy, coolants, water, and air counted by number or duration of processes
- Emissions and waste counted by number or duration of processes

The term process should be viewed widely i.e. any duration of time is considered as a process, and the chain of processes makes the total time. Therefore, from a viewpoint of a product, the process consists of work, transfers between resources, and waiting times in buffers and storage areas. The time when the processes can happen are limited by a factory calendar. It consists of working days and days off, such as public holidays. Each work day consists of number and duration of shifts. Similarly, each shift has number of breaks for coffee and lunch.

In many cases, a company offers a wide range of products because they are customised to individual customer requirements. Typically, many products are similar, and for factory simulation, can be simplified to a few products that present the whole product portfolio in a sufficient level. Input parameters, describing the characteristics and properties of products are, for example:

- Weight, dimensions, and shape of the products
- Material properties and tolerances
- Amount of removed material
- Material cost
- Processes that are required in order to manufacture the products

The resources of a factory simulation are required to cover all phases that are needed for manufacturing the products that are included in a simulation model. Typical examples of input parameters, related to manufacturing resources, are:

- Number and types of resources for work, transferring and storing products
- Sizes of work in progress buffers and storage areas
- Distances and transfer routes between resources
- Resource capabilities e.g. what processes a machine can perform
- Failures and repair times as well as planned maintenance breaks
- Use of energy in different states and with different process parameters
- Skills of workers capable of operating multiple machines
- Absences of personnel such as sick leaves or training to improve skills and know-how

In addition to the presented input parameters, there is several important parameters that cannot be directly assigned to them. Examples of these are heating, cooling, and ventilation as well as services such as maintaining the facilities.

Orders

Orders present the instances of ordered products that appear into a simulation model, flow thru their chain of processes, and at the end disappear from the simulation model. The orders utilize the input information related to the products, processes, and resources. Their appearances into a model can be based on, for example:

- Real production program that is simplified based on the simplified products
- Production program with changed volume and variation of orders based e.g. on forecasts or predictable trend of customer behaviour.
- “What-if” –analysis of different scenarios to analyze the system capabilities and capacity in specific situations.

To make the orders flow thru the simulation model, it is required to know the conditions when a process can start and to know when a process has ended. Going from a process to next requires having criteria for selecting the next process. These include rules and logics to select from parallel resources as well as selecting alternative routes if available. The criteria can be based on goals and objectives, such as finding the fastest, cheapest, or greenest alternative.

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