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## Design and planning of manufacturing networks for mass customisation and personalisation: Challenges and Outlook

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### Abstract

Manufacturers and service providers are called to design, plan and operate globalized manufacturing networks, addressing to challenges such as ever-decreasing lifecycles and increased product complexity. These factors, caused primarily by mass customisation and demand volatility, generate a number of issues related to the design and planning of manufacturing systems and networks, which are not holistically tackled in industrial and academic practices. The mapping of production performance requirements to process and production planning requires automated closed-loop control systems, which current systems fail to deliver. Technology-based business approaches are an enabler for increased enterprise performance. Towards that end, the issues discussed in this paper focus on challenges in the design and planning of manufacturing networks in a mass customization and personalization landscape. The development of methods and tools for supporting the dynamic configuration and optimal routing of manufacturing networks and facilities under cost, time, complexity and environmental constraints to support product-service personalization are promoted.

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*Keywords:* Manufacturing Systems and Networks; Product-Services; Design, Planning and operation

### 1. Introduction

The changes in the economic, political and technological landscape during the last thirty years, have drastically affected manufacturing. The traditional localized and centralized manufacturing transformed into a globalized and decentralized paradigm. Stable markets, at the same time, become highly volatile and unpredictable [1]. The role of customer changed from that of a product buyer to an integrated entity in the product design and development.

Currently, manufacturers and service providers are presented with challenges such as reduced product life cycles, increased product, service and system complexity, and immense pressure from global competition [2]. These challenges are partly generated by the highly volatile demand and exploding product variety introduced by the mass customisation and product personalisation paradigms. Their impact on the design and operation of modern globalized

manufacturing networks is evident [3]. Consequently they also heavily affect the operation of individual facilities.

The emergence of new materials, new forms of production and key enabling technologies make new diversified product features and processes feasible, as well as allow the interconnection between IT systems, humans and engineering / manufacturing phases.

The management of the co-evolution of product, process and production on a strategic and operational level is a huge challenge however, the manufacturing domain in general lacks of unified solution approaches [4].

Towards this end, technology-based business approaches comprise a major enabler for the realization of robust manufacturing systems and networks that offer high-value value-added, user-oriented products and services. Design, planning and control support systems with inherent robustness are necessary in order for companies to withstand the antagonism through sustainable practices.

### 1.1. Review Methodology

The review approach is based on a search among academic journals, articles and books, primarily in the Scopus and Google Scholar databases, using as keywords the main fields of interest, namely: evolution of manufacturing paradigms, issues of mass customization and personalization environments, the role of simulation for manufacturing, methods and technologies related to product and production complexity, inventory management and capacity planning, among others.

Academic peer-reviewed publications related to the above fields were selected, ranging over a period of 30 years, from 1984 to 2014, with only a few notable exceptions.

Sciences that were included in the search were: engineering, management, business, and mathematics. The review was carried out in three stages: (a) search in scientific databases (Scopus and Google Scholar) with relevant keywords, (b) identification of relevant papers by abstract reading and (c) full-text reading and grouping into research topics.

Indicatively, the frequency of results from a search with the keywords “mass customization” or “product personalization” in the abstract, title and keywords of the article as obtained from the Scopus database, is depicted in Fig. 1. This figure also visualizes the increase of interest on these topics by the scientific community.

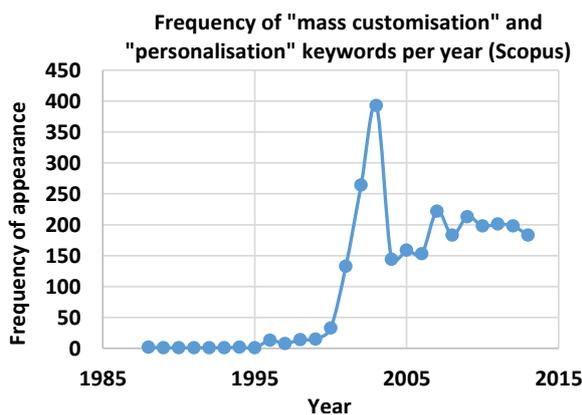


Fig. 1. Frequency of appearance of the keywords “mass customization” and “personalization” in the abstract, title and keywords of the article (obtained from Scopus)

## 2. State of the Art: Challenges and Practices

Globalization in manufacturing activities, apart from its apparent advantages, introduces a set challenges. On one hand, a globalized market offers opportunities for expanding the sphere of influence of a company, widening its customer base and production capacity. Information and Communication Technologies (ICT) and the Internet has played a significant role to that [5]. On the other hand, regional particularities greatly complicate the transportation logistics and the identification of optimum product volume procurement, among other. Indicatively, the difficulty in

forecasting product demand, was highlighted as early as in 1986 by the following observation from Intel labs: when investigating the match between actual call off and the actual forecast, estimated that supply and demand were in equilibrium for only 35 minutes in the period between 1976 to 1986 [6][7].

Enterprises started locating their main production facilities in countries with favourable legislation and low cost of human labour [8], thus, the management of the supply chain became extremely complex, owing primarily to the fact that a great number of business partners have to mutually cooperate in order to carry out a project, while being driven by opportunistic behaviour. Thus, manufacturing networks need to properly coordinate, collaborate and communicate in order to survive [9].

On a manufacturing facility level, the impact of supply chain uncertainties and market fluctuations is also heavy. The design and engineering analysis of a complex manufacturing system is a hard task and its operation becomes even harder when flexibility and re-configurability parameters must be incorporated [10]. The process is iterative and can be separated into smaller task of manageable complexity. Resource requirements, resource layout, material flow and buffer capacity are some of these tasks [11]. Even when decomposed and relaxed through, production planning, assembly line balancing and sequencing are challenging tasks [12].

Especially in the context of production for mass customization businesses, issues such as task-sequence dependent inter-task times between product families are usually ignored, leading to inexact and in many cases non-feasible planning and scheduling. Even rebalancing strategies for serial lines with no other interdependencies is a difficult task, with ample room for improvement in order for the inconsistencies between process planning and line balancing to be minimized [13].

From a technological perspective, the increased penetration of ICT in all aspects of product and production life-cycle enable a ubiquitous environment for the acquisition, processing and distribution of information. With the introduction in manufacturing of the concepts of Cyber-Physical Systems (CPS) and Internet of Things (IoT) [14], new horizons are presented for improving awareness, diagnosis, prognosis and control.

Also, the relatively new paradigm of agent-based computation provides great potential for realising desirable characteristics in production, such as autonomy, responsiveness, distributiveness and openness [15].

### 2.1. Evolution of Manufacturing Paradigms

Historically, manufacturing paradigms, driven by the change of the environment in which they operate, change in character and evolve in patterns over time (Fig. 2). The various patterns witnessed up to now can be roughly correlated to movements between three stages: (i) craft shops that employ skilled artisans, (ii) long-linked industrial systems using rigid automation and (iii) post-industrial enterprises characterised by flexible resources and information intensive

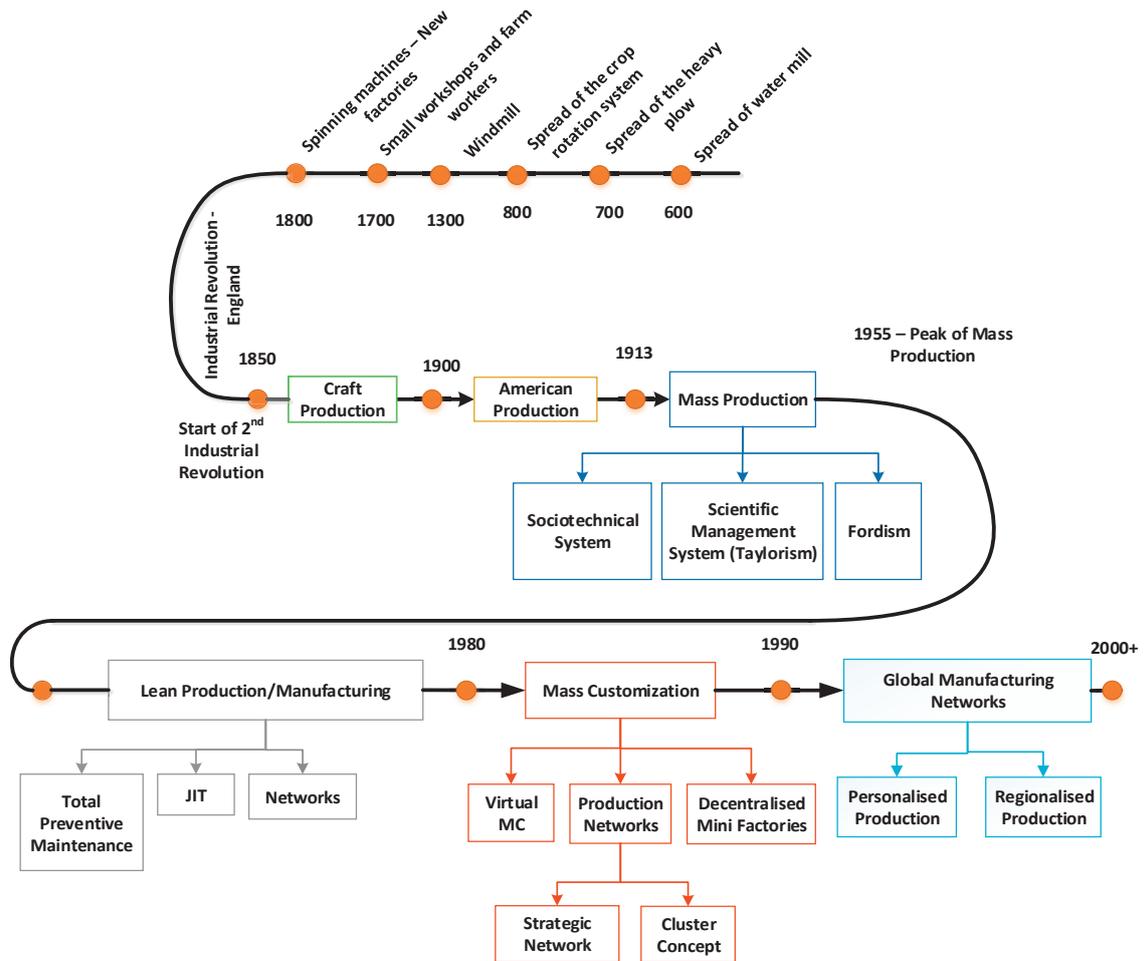


Fig. 2. The evolution of Manufacturing Paradigms (Adapted from [1])

intellectual work [16]. The most prevailing manufacturing paradigms are in chronological order of appearance: Craft Production, American Production, Mass Production, Lean Production, Mass Customisation and Global Manufacturing. Apart from American Production, all other paradigms are still “operational” today in different industrial sectors [1].

Research nowadays focuses on strategies and methods for managing product, process and production systems development capable of supporting lean production, mass customization and systems for product personalization.

Lean production is an integrated socio-technical system, whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability [17]. Specific industry types may benefit from a combined implementation of agile and lean practices in their organisation [18]. However, a point in the production procedure should be defined, where these concepts can be easily decoupled according to the incoming demand. This can lead to improved overall performance and profitability of the factory.

Mass customization emerged as a new production paradigm in the late 1980s in order to respond to consumer demands for product variety and appears as an alternative to differentiate companies in a highly competitive and segmented market [19][20][21]. This paradigm aims at producing goods and services catering to individual customer’s selections with near mass production volume and cost efficiency. The tools of mass customisation can substantially enable product personalisation [22].

Personalised production aims at the procurement of truly unique products, through the tight integration of the customer in the design process. However, to make personalized production a cost effective reality, several enabling technologies and features must be developed, such as: methods and tools for understanding and capturing consumers’ needs and preferences, design by non-designers techniques, cyber-physical systems for collaboration, on-demand manufacturing and assembly systems, process, product, volume and production flexibility [9] among other.

Manufacturing experienced notable changes and transitions, attributed to the pressure from social and political

situations and advances in technology. By studying these transitions, it is noticeable that the factory systems and technologies have been evolving in two directions. Firstly, they increased the versatility of the allowable products variety that they produced. This resulted in numerous production innovations, design technology advances and evolution in management techniques. Secondly, companies have extended factories like tools and techniques. Factories emerged from firms that introduced a series of product and process innovations that made possible the efficient replication of a limited number of designs in massive quantities. This tactic is widely known as economies of scale [23]. Factory systems replaced craft modes of production as firms learned how to rationalise and product designs as well as standardize production itself [24]. Although factory organisations provided higher worker and capital productivity, their structure made it difficult to introduce new products or processes quickly and economically, or to meet the demands of customers with distinctive tastes; factory-oriented design and production systems have never completely replaced craftsmanship or job shops even if the new technologies continue to appear. The result, in both manufacturing and design has been a shift from simple economies of scale, as in the conventional mass production of a limited number of products, to economies of scope and integration [25]. It is clear that mass-production factories or their analogies, are not appropriate for all types of products or competitive strategies. Moreover, they have traditionally worked best for limited numbers of variants suited to mass replication and mass consumption. The craft approach offers a less efficient process at least for commodity products but remains necessary for technologies that are still new or emerging and continues to serve specific market niches, such as for tailoring products for individual needs and luxury or traditional items.

Naturally, even if the trends dictate a shift towards personalized product requirements, it should always be considered that forms of production such as mass production cannot be abandoned for commodities and general purpose products, raw materials and equipment. After all, paradigms are shaped to serve specific market and economical situations.

A categorization of the different production concepts based on the indicators: system re-configurability, demand volatility and product complexity is depicted in Fig. 3.

Today, issues introduced by the shift of business models towards online purchasing and customisation [26], must be tackled in cost-efficient and sustainable ways in order for companies to maintain their competitiveness and create value [27]. To respond to consumer demand for higher product variety, manufacturers started to offer increased numbers of product “options”, or variants of their standard product [29]. Mass customization (MC) is a production strategy focused on the broad provision of personalized products and services, mostly through modularized product/service design, flexible processes, and integration between supply chain members [20][21]. MC targets Economies of Scope through market segmentation, by designing variants according to a product family architecture and allowing customers to choose between design combinations [13].

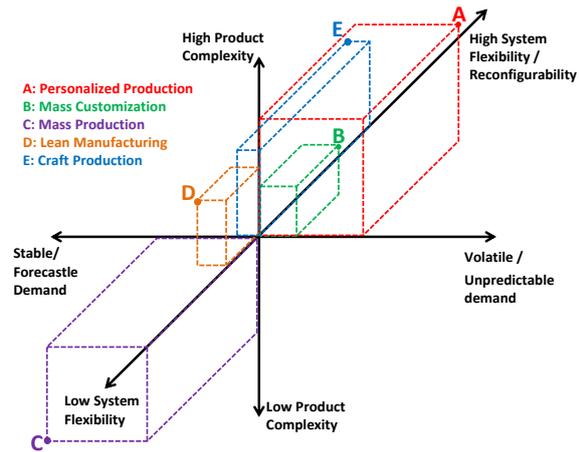


Fig. 3. Characterisation of production paradigms based on market demand, product complexity and flexibility

At the same time however, MC must achieve Economies of Scale, in a degree compared to that of mass production, due to the fact that it addresses a mass market. Another significant objective for companies operating in an MC landscape is the achievement of Economies of Integration in order to improve the performance in the dimension of costs [25]. On the other hand, personalized production aims to please individual customer needs through their direct integration in the design of products. The major differences between the prominent paradigms of mass production, mass customization and personalization are depicted in Fig. 4.

	Mass production	Mass customization	Personalization
<b>Goal</b>	Economy of Scale	Economy of scope	Value differentiation
<b>Customer involvement</b>	Buy	Choose	Design
<b>Production System</b>	Dedicated Manufacturing System (DMS)	Reconfigurable Manufacturing System (RMS)	On Demand Manufacturing System
<b>Product Structure</b>	Common parts	Common parts / Custom parts	Common parts / Custom parts / Personalized Parts

Fig. 4. Differences between production paradigms (Adapted from [13])

2.2. Impact of Mass Customization and Product Personalization on Contemporary Manufacturing

A research conducted in the U.K. related to automotive products revealed that 61% of the customers wanted their vehicle to be delivered within 14 days [30], whereas consumers from North America responded that they could wait no longer than 3 weeks for their car, even if it is custom built [31]. Such studies point out the importance of

responsiveness and pro-activeness for manufacturers in product and production design.

During the last fifteen years the number of online purchases has increased and recent surveys show, that 89% of the buyers prefer shopping online to in-store shopping [32]. Web-based and e-Commerce systems have been implemented, and have proved to be very effective in capturing the pulse of the market [33]. These web-based toolkits aim at providing a set of user-friendly design tools that allow trial-and-error experimentation processes, and deliver immediate simulated feedback on the outcome of design ideas. Once a satisfactory design is found, the product specifications can be transferred into the firm's production system, and the custom product is subsequently produced and delivered to the customer [34].

The incorporation of the customers' unique tastes in the product design phase is a fairly new approach to the established ways of achieving product variety and entails significant reorganisation, reconfiguration and adaptation efforts for the company's production system. Variety is normally realised at different stages of a product lifecycle. It can be realised during design, assembly, at the stage of sales, and through adjustments at the usage phase. Moreover, variety can be realised during the fabrication process e.g. through rapid prototyping [35].

Still online 2D and 3D configurators do not solve practical issues such as the assembly process of these unique variants. Although proposed approaches include e-Assembly systems for collaborative assembly representation [36] and web-based collaboration systems [37], the research in this area needs to be expanded in order to provide tools for assembly representation and product variant customization. An additional constraint is that globalized design and manufacturing often require the variants for local markets to be generated by regional design teams, which use different assembly software and supply bases [13].

### **3. Modern Manufacturing Network Design and Planning along the Manufacturing Network Life-cycle**

A modern manufacturing network is composed of cooperating OEM plants, suppliers and dealers that produce and deliver final products to the market [38]. An example of an automotive manufacturing network focused on product assembly is depicted in Fig. 5. The automotive sector is a typical industry that relies on globalised value-adding networks. This section gives an overview on aspects of manufacturing networks design and planning. The topics discussed consist of: partner selection, supply chain coordination, initial network configuration, manufacturing network complexity, inventory management, capacity planning, warehousing, dynamic process planning and monitoring and control. These topics are in line with the lifecycle phases of a manufacturing network as reported in [39], and a relative search in scientific databases yields results that can be grouped into these life-cycle phases.

#### *3.1. Partner Selection*

The building blocks of any manufacturing network are the cooperating companies. The significance of the selection of partners (supplier, vendors) has been indicated as early as in 1966 and is stressed in [40]. This decision-making problem is highly challenging and often it is broken down into sub-problems of manageable complexity, such as formulation of criteria for the selection, qualification of partners, final selection and feedback verification. A comprehensive literature review on the issue of partner selection in agile manufacturing chains is included in [41].

#### *3.2. Supply Chain Coordination*

The alignment of the objectives of the different collaborating organisations in order to successfully carry out projects, optimize system performance and achieve mutual profits is indispensable [42]. As an entity, a supply chain requires a total systems approach to managing the entire flow of information, materials and services in fulfilling customer demand [43].

In general, supply chains are categorized into two categories, namely centralised and decentralised [1]. In the first, the decisions are taken by a central body, often the leading supply chain OEM, whereas in the second, each member independently makes its own operational decisions. The tools for coordinating partners within such diverse paradigms are evidently diverse. While an action plan suffices for the coordination of a centralised supply chain, it is inadequate with a decentralised one [44]. Further incentives have to be provided to the members, so as entice their cooperation through e.g. distribution of the benefits of the coordination. The need for adaptation to the new requirements has led to the definition of a novel framework for autonomous logistics processes. The concept of autonomous control "describes processes of decentralised decision-making in heterarchical structures, and it presumes interacting elements in non-deterministic systems, and possess the capability and possibility to render decisions independently [45]".

Still a serious gap in recent approaches is the lack of synergistic methods that combine the benefits found in analytical models and simulation models. A potential solution was proposed in [46] as a two-step procedure. The initial step was the overall analysis of the logistics performance of the production system using the logistics operating curves. This step identifies the opportunities for performance improvement and can act as the input to the second step, which is the detailed examination of what-if scenarios through simulation and potential performance gains.

#### *3.3. Initial Manufacturing Network Configuration*

The initial manufacturing network configuration must consider the long-term needs of cooperation and often determines its success. The problem has been extensively addressed in literature using approaches classified in two main categories, namely approximation and optimization techniques. The first category includes: iterative methods such

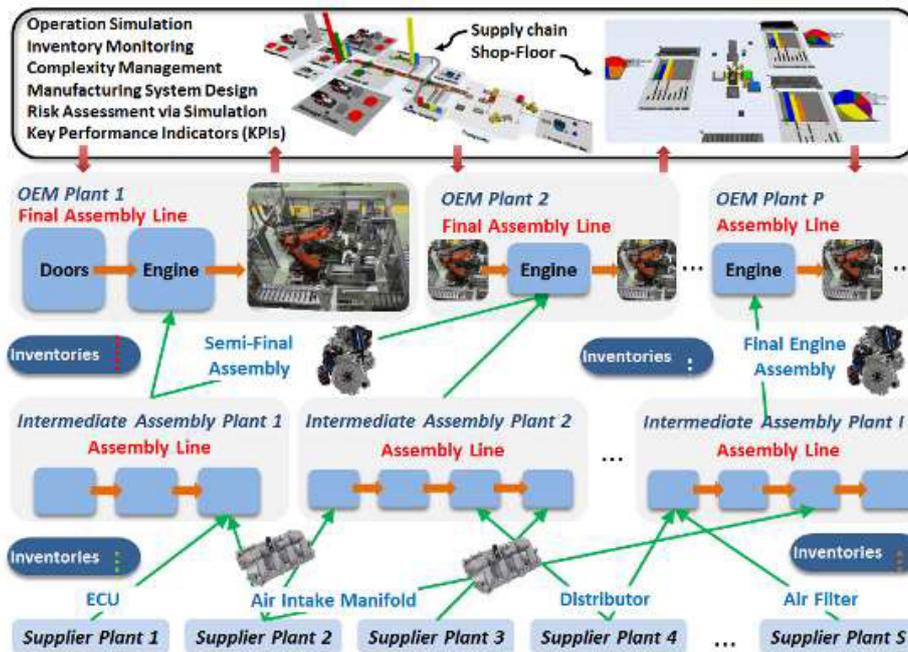


Fig. 5. An assembly concept in a globalized manufacturing network from automotive industry

as artificial intelligence, evolutionary computation, genetic algorithms, Tabu search, ant colony optimization, simulated annealing and constructive methods (heuristics, dispatch rules etc.). The second category includes: enumerative methods (Lagrangian relaxation, linear / non-linear integer programming) and decomposition methods. Moreover, there exist hybrid methods that combine two or more of the aforementioned methods [47]. Mixed-integer mathematical methods that aim at optimizing a set of performance indicators have been proposed [48]. Fuzzy mathematical programming techniques have been employed to address the planning problems in supply chains [49]. A multi-criteria decision making method to support the identification of business to business (B2B) collaboration schemes, especially for supplier selection was proposed in [50]. A coloured Petri Nets approach for providing modelling support to the supply chain configuration issue is included in [51]. A dynamic optimization mathematical model for multi-objective decision making for manufacturing networks that operated in a mass customization environment was suggested in [52]. A literature review on mathematical programming for planning of supply chains is documented in [53] and a report on coordination mechanisms for supply chains was compiled in [54].

### 3.4. Manufacturing complexity management

Complexity is a long studied subject [55] and several approaches have been proposed especially for modelling and measuring the product and manufacturing complexity. The majority of these approaches can be classified in five categories, based on the domains that they draw their inspiration, the tools and characteristics, namely: information

theoretic entropic-based [56], time series analysis utilizing tools such as: Fourier analysis and non-linear dynamics [57][58] and approaches inspired by computational mechanics [59], complexity analysis based on axiomatic theory [55], methods that attempt to address complexity by defining a coding system for machines and products [60][61], and methods inspired fluid dynamics, introducing an analogy to the Reynolds number for manufacturing systems, in order to define the threshold between a steady and a turbulent behaviour [62]. Complexity study has attracted great interest and studies deal with the emerging aspects of increasing complexity of manufacturing activities and the dynamic nature of supply chains [63]. The importance of managing the complexity in supply chains is evident, as recent studies depict that lower manufacturing network complexity is associated with reduced costs and overall network performance [64] [38]. A complete and comprehensive review of complexity in engineering design and manufacturing is presented in [65].

### 3.5. Inventory Management / Capacity Planning

Inventories are used by most companies as a buffer between supply chain stages to handle uncertainty and volatile order demands. Prior to the 90s', where the main supply chain phases, namely procurement, production and distribution were regarded in isolation, companies maintained buffers of large inventories due to the lack of regulatory mechanisms and feedback [66]. Various strategies for inventory planning have been reported based on how the underlying (known) demand and return processes are modelled over time, thus making a distinction between constant, continuous time-varying, and discrete time-varying demand and return models [67].

Integrated capacity planning methods encompassing stochastic dynamic optimization models over volatile planning horizons exhibit high performance in the context of mass customization and personalization [68]. The DEWIP (Decentralised WIP) control mechanism was proposed by [69], focusing on establishing control loops between work-centres for adjusting the WIP levels dynamically. Its performance was assessed against other well received systems such as LOOR, Conwip and Polca.

### 3.6. Enterprise Resource Planning

An Enterprise Resource Planning (ERP) system is a suite of integrated software applications used to manage transactions through company-wide business processes, by using a common database, standard procedures and data sharing between and within functional areas [70]. Such IT systems entail major investments and involve extensive efforts and organizational changes in companies that decide to employ them. ERP systems are becoming more and more prevalent throughout the international business world. Nowadays, in most production distribution companies, ERP systems are used to support their production and distribution activities and they are designed to integrate and partially automate financial, resource management, commercial, after-sale, manufacturing and other business functions in to one system around a database [71]. A literature-based and theory-driven model was developed in order to test the relationship between ERP system implementation status and operational performance [72]. Moreover, a general-risks taxonomy for ERP maintenance is investigated with the use of analytic hierarchy process [73]. An objectives-oriented approach with one evaluation model and three optimisation models addresses key management issues in the implementation of critical success strategies (CSSs) to ensure the success of an ERP project [74]. In order to deal with the problem of

independence in risk assessment, an approach using Coloured Petri Nets is developed and applied to model risk factors in ERP systems [75]. At the heart of currently used closed-loop MRPII and ERP production planning systems deployed in manufacturing enterprises, lies the fundamental MRP logic [11][76]. Still, reported successful implementations of ERP systems are limited when considering implementation costs and disruptions caused in production [77]. A main reason for that is commonly attributed to the fact that MRP-based systems do not produce detailed shop-floor schedules, and most of them assume infinite production capacity, thus using inflated and constant lead times [78].

## 4. The Role of Simulation in Manufacturing

### 4.1. The importance of Simulation for the Design and Planning of Manufacturing Networks Lifecycle

A supply chain is the value-adding chain of processes from the initial raw materials to the ultimate consumption of the finished product spanning across multiple supplier-customer links [87]. Robust and flexible system mechanisms are required to realize such inter-enterprise collaboration environments often enabled by the use of simulation technology. Digital Enterprise Technologies (DET) in general, represent an established, new synthesis of technologies and systems for product and process development and life-cycle management on a global basis [88].

A method to model, simulate and optimize supply chain operations by taking into consideration their end-of-life operations is used to evaluate the capability of OEMs to achieve quantitative performance targets defined by environmental impacts and costs of lifecycle [89]. A method of examining multi objective re-configurability of an Original Equipment Manufacturer supply chain is presented in order to

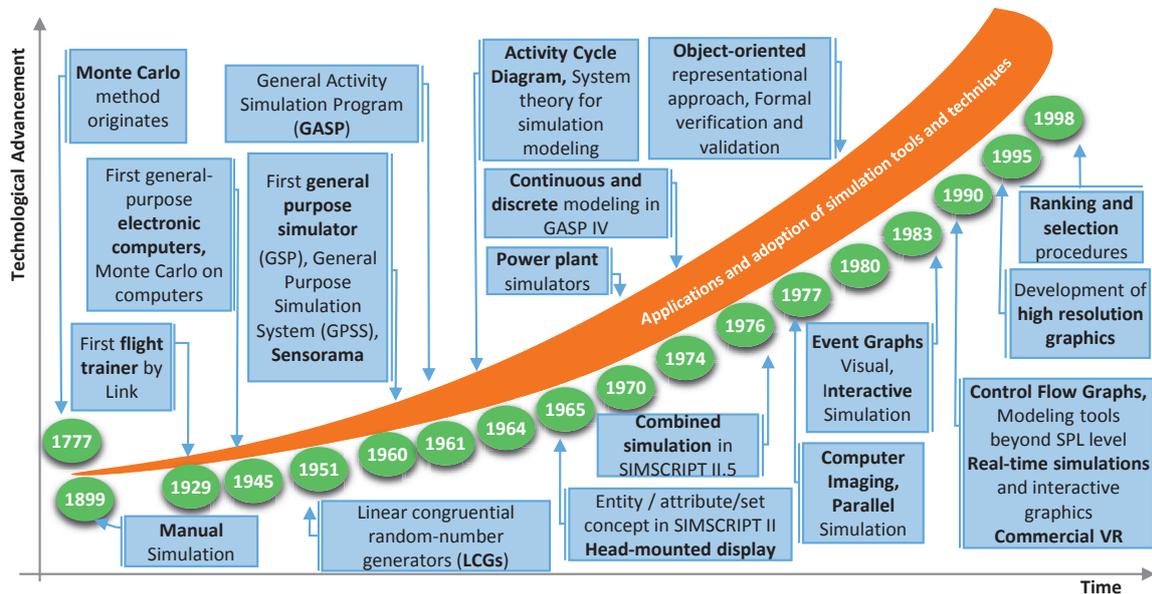


Fig. 5. The evolution of simulation (Adapted from [80])

adapt with flexibility dynamically changing environmental restrictions and market situations [90]. A discrete-event simulation model of a capacitated supply chain is developed and a procedure to dynamically adjust the replenishment parameters based on re-optimisation during different parts of the seasonal demand cycle is explained [91]. A model is implemented in the form of Internet enabled software framework, offering a set of characteristics, including virtual organisation, scheduling and monitoring, in order to support cooperation and flexible planning and monitoring across extended manufacturing enterprise [42]. Furthermore, the evaluation of the performance of automotive manufacturing networks under highly diversified product demand is succeeded through discrete-event simulation models in [28] with the use of multiple conflicting user-defined criteria such as lead time, final product cost, flexibility, annual production volume and environmental impact due to product transportation. Finally, the application of the mesoscopic simulation approach to a real-world supply chain example is illustrated utilizing the software MesoSim [92][93].

#### 4.2. Historical Evolution of Simulation

Although the term “Monte Carlo method” was coined in 1947, at the start of the computer era, stochastic sampling methods were used long before the evolution of computers [79]. It is widely acknowledged that the contemporary meaning of simulation originated with the work of Comte de Buffon in the 18<sup>th</sup> century, who developed a Monte Carlo-like method and used it to determine the outcome of an experiment consisting of repeatedly tossing a needle onto a ruled sheet of paper. The aim of the experiment was to calculate the probability of the needle crossing one of the lines [80]. About a century later, Gosset used a primitive form of manual simulation to verify an assumption about the exact form of the probability density function for Students t-distribution [81]. In the mid-1940s, simulation makes a significant leap with the contribution of the first general-purpose electronic computers. Ulam, von Neumann and Metropolis use Monte Carlo on computers to solve problems concerning neutron diffusion. Tochter and Owen develop the General Simulation Program in 1960, which is the first general purpose simulator to simulate an industrial plant that consists of a set of machines, each cycling through states as busy, idle, unavailable and tailed [82]. During the period 1960-1961, Gordon introduces the General Purpose Simulation System (GPSS) [81]. Simultaneously, Nygaard and Dahl initiate work on SIMULA and they finally release it in 1963 and Kiviat develops the General Activity Simulation Program (GASP). Although, a significant evolution of simulation is noticed, there are still problems concerning model construction and model analysis which are mentioned and addressed by [83]. Moreover, Bryant initiates parallel simulation [84]. In the beginning of the 1980s, major breakthroughs take place, military flight simulators, naval and submarine simulators are produced and NASA develops relatively low-cost VR equipment [85]. In early 1990s, real-time simulations and interactive graphics become possible due to the increased computer power and commercial VR applications become feasible [86]. In

addition, the development of high-resolution graphics focuses on gaming industry surpassing in that way the military industry [85]. The historic evolution of simulation is depicted in Fig. 5.

### 5. Cloud Manufacturing

Cloud technology and the Internet of Things are major trends that will reshape the way enterprises function in the years to come [94][95]. A comprehensive definition of cloud computing is provided by the National Institute of Standards and Technology: “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” [96]. Several applications have been reported in recent years where a Cloud infrastructure is used to host and expose services related to manufacturing, such as: machine availability monitoring [97], collaborative and adaptive process planning [98], online tool-path programming based on real-time machine monitoring [99], manufacturing collaboration and data integration based on the STEP standard [100] and collaborative design [101]. This technology has recently attracted a lot of attention in the European community as strategic agendas are being prepared for unleashing the potential of cloud computing in the industrial domain [102].

The cloud delivery models have been classified into the following: (i) Software-as-a-Service, where software is licensed on a subscription basis and is centrally hosted on the cloud, (ii) Platform-as-a-Service, that provides a computing platform and a set of software subsystems or components required to perform a task without further external dependencies, and (iii) Infrastructure-as-a-Service, which outsources the physical equipment used to support computing operations, including storage, hardware, servers and networking components. The combination of existing services for the creation of novel ones, which is called a Cloud mash-up, is also a promising means of tailoring services to the exact needs of the company (Fig. 6). Therefore, everything in the cloud can be perceived as a purchasable service, hence the notion Everything-as-a-Service (XaaS).

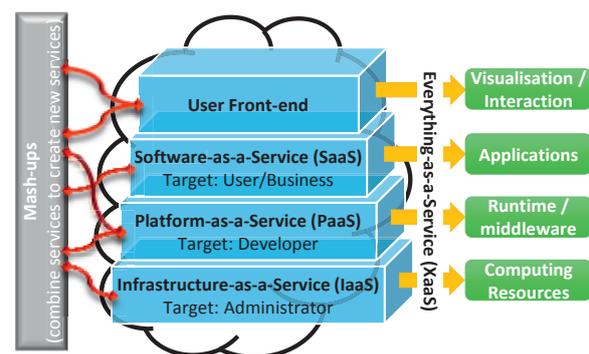


Fig. 6. Everything-as-a-Service Cloud Architecture (Adapted from [95])

The benefits of Cloud for manufacturing enterprises are numerous. Cloud can offer increased mobility and ubiquitous information to an enterprise since the solutions it offers are device and location independent. Moreover, computational resources are virtualized, scalable and available at the time of demand. Therefore, the intensive costs for deploying high-performance computing resources are avoided. In addition to that, purchasing the application using the model Software-as-a-Service is advantageous for SMEs who cannot afford the huge investments that commercial software suites entail [103].

However, there are some considerations also. A main challenge for the adoption of Cloud in manufacturing is the lack of awareness on security issues. Companies that utilise Cloud solutions are providing some control of their data to an external third source [121]. The concerns on security issues are evidenced by the fact that the global cloud software security market is rapidly growing and it is predicted to reach US\$ 3 billion by 2018 (Fig. 7).

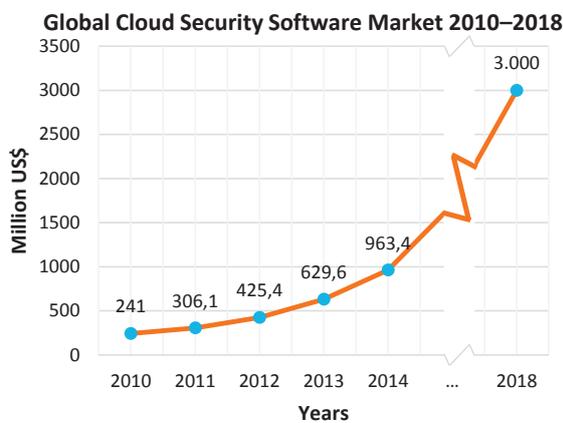


Fig. 7. Global Cloud Security Software Market Forecasts 2010 – 2018 (Source: TechNavio Analysis 2011 [121], and MindCommerce 2013 [122])

This major issue of security can be addressed using security concepts and inherently safe architectures, such as private Clouds. The security concept will include availability of Information Technology (IT) systems, network security, software application security, data security and finally operational security. Moreover, there is the possibility of backlash from entrenched ideas, manufacturing processes and models caused by the hesitation for the adoption of innovative technology. Finally, the lack of standardisation and regulation around Cloud hinders its acceptance by the industry [104].

### 6. The Proposed Holistic Framework

Mass customisation and personalisation are at the centre of research and industrial interest. The issues they generate on a design, planning and control level, call for robust methods and tools. To support manufacturing network design, planning and control, a framework that integrates, harmonizes, processes and synchronizes the different steps and product related information is needed (Fig. 8). The framework will be capable

of supporting the decision-making procedure on all organization levels in an integrated way, ranging from the overall management of the manufacturing network, down to the shop-floor scheduling. An alignment and coordination between supply chain logistics, master production schedules with low level shop floor schedules is necessary for short-term horizons. The integration of a material planning logic with the production planning system is also important. Consideration of capacitated production constraints is needed in order to reflect realistic system attributes. Moreover, a shared and distributed intra-departmentally inventory record will contain information related to MRP and ERP variables (e.g. projected on hand quantities, scheduled order releases and receipts, changes due to stock receipts, stock withdrawals, wastes and scrap, corrections imposed by cycle counting, as well as static data that describe each item uniquely). Assembly Line Balancing (ALB) techniques will be introduced supported by assembly sequence algorithms and process planning optimisation.

The measurement of the manufacturing network complexity towards handling a variety of market excitations and demand fluctuations is a required feature. Complexity should be incorporated as a cost criterion in the decision-making process during the design of manufacturing systems and networks. In parallel, a risk assessment engine should correlate complexity results and leverage them into tangible risk indicators. Complexity can be efficiently channelled through the designed network in the less risky and unpredictable manner.

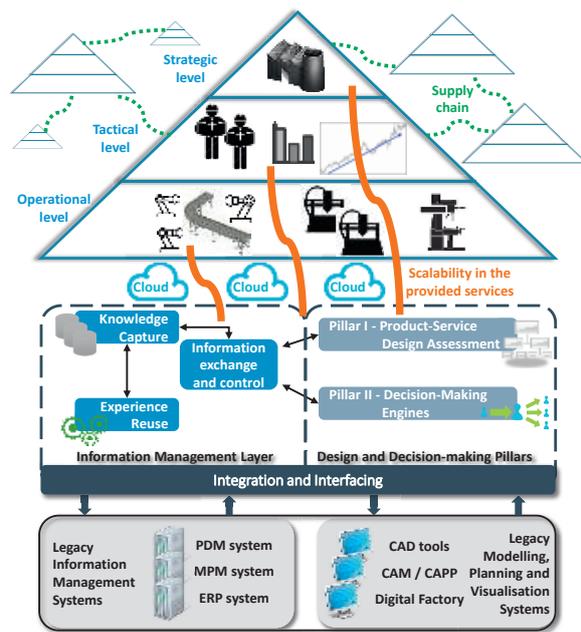


Fig. 8. The proposed holistic framework

In parallel, the standardization of data representation for manufacturing information such as: the product information (BoM, engineering-BoM and manufacturing-BoM [118]), the

manufacturing processes (Bill of Processes - BoP) including the manufacturing facilities layout, the associated relations (Bill of Relations – BoR) and related services (Bill of Services – BoS) should be pursued through a shared data model. Moreover, the product complexity needs to be assessed based on functional product specifications using Design Structure Matrices (DSM) [119], which incorporate components (BoM), the required manufacturing and assembly processes (BoP) including sequences / plans, relationships (BoR), and the accompanying services (BoS). The complexity of the product in relation to the manufacturing network and service activities (impact on delivery time, on cost and effect on the overall reliability) will be quantified in will be incorporated in the decision making process. Another aspect that will be tackled would be the division of strategies for variety management to allow the sharing of same parts between different product configurations (i.e. families), effectively reducing the number of individual parts to be managed.

The system will be supported by an automated model-based decision-making method that will identify optimum (or near optimum) configurations of manufacturing networks capable of serving personalized product-services. The method must consider the capabilities of the manufacturing network elements (suppliers of different tiers, machining plants, assembly plants etc.) and will indicate solutions to the warehouse-sizing problem, to the manufacturing plant allocation and to the transportation logistics. The decision support framework requires interfacing with discrete event simulation models of manufacturing networks and assessment of multiple conflicting and user-defined performance indicators. Classical indicators should always be considered, such as production and transportation cost, quality, manufacturing and transportation lead time, and other indicators of contemporary importance should be integrated, such as static and dynamic complexity, reliability, flexibility and adaptability.

Interfacing of legacy software systems and databases for seamless data exchange and “collaboration”. CAD/CAM, PDM and MPM systems and databases will be interfaced and interact with digital mock-ups of the factory and product-services solutions as well. All data should be stored in semantic repositories accompanied with knowledge inference mechanisms. The deployment and tight integration of PLM tools is also must be considered since they bring an abundance of benefits against current manufacturing challenges. Yet these benefits are still not appreciated by many industrial sectors, such as the automotive, mainly due to the following reasons: (i) they are complex as a concept and understanding their practical application is difficult, (ii) they lack a holistic approach regarding the product lifecycle and its underlying production lifecycle and processes, and (iii) the gap between research and industrial implementation is discouraging [120].

It should be noted here that the components of the proposed framework will be offered following a Software-as-a-Service delivery method. The framework should act as a Cloud-based hub of different solutions, offering web-based accessibility through a central “cockpit” and visualization of results through common browser technology and handheld devices (tablets, smartphones etc.).

Last but not least, the knowledge capturing and exploitation is pivotal in the proposed framework. Product, process and production information is acquired from production steps and is modelled and formalized in order to be exploited by an experience reuse mechanism. This mechanism is comprised by an ontological model that is queried by the knowledge inference engine and allows the retrieval of knowledge and its utilization is design and planning phases.

## 7. Conclusions and Challenges for the Manufacturing of the Future

Based on the literature review, the following general challenges, tightly connected to the big game changers for manufacturing, are identified:

- Challenges on the technological level of ERP systems, include delivery of software as a service, mobile technology, tightly integrated business intelligence and big data analytics [105][106].
- Challenges in the field of Product Data Management (PDM) are related to the efficiency of these systems with regards to studying factors that affect the accessibility of product data. For instance, the nature of data in different timeframe of a development, the relationship between the maturity of the data and the probability of them being modified [107].
- Limitations of current Computer-Aided Design (CAD) tools include: the complexity of menu items or commands, restricted active and interactive assistance during design, and inadequate human-computer interface design (focused on functionality) [108].
- To fulfil the needs of modern manufacturing processes, computer-aided process planning should be responsive and adaptive to the alterations in the production capacity and functionality. Nowadays, conventional CAPP systems are incapable of adjusting to dynamic operations and a process plan, created in advance, is found improper or unusable to specific resources [109].
- Highlighted challenges for Lifecycle Assessment (LCA) are modularisation and standardisation of environmental profiles for machine tools, as well as modelling of “hidden flows” and their incorporation in value stream mapping tools [110][111].
- Regarding knowledge management and modelling, reusable agent-oriented knowledge management frameworks, including the description of agent roles, interaction forms and knowledge description are missing [112]. Moreover, ontologies used for knowledge representation have practical limitations. In case an ontology is abstract, its applicability and problem solving potential may be diminished. On the other hand, in the case of very specific ontologies, reasoning and knowledge inference capacities are limited [113].
- In the turbulent manufacturing environment, a key issue of modern Manufacturing Execution Systems is that they cannot plan ahead of time. This phenomenon is named decision myopia and causes undoubtedly significant malfunctions in manufacturing [114].

- On the field of supply chain management, identifying the benefits of collaboration is still a big challenge for many. The definition of variables, such as the optimum number of partners, investment in collaboration and duration of partnership, are some of the barriers of healthy collaborative arrangements that should be surpassed [115].
- Finally, in the field of layout design and material simulation, some commercial software can represent decoupling data from 3D model and export them in XML or HTML format. While this is an export of properties, this cannot fully solve the interoperability and extensibility issues since the interoperability depends on how the different software and users define contents of data models [116]. Moreover, while the steady decline in computational cost renders the use of simulation very cost-efficient in terms of hardware requirements, commercial simulation software has not kept up with hardware improvements. Concerning material flow simulation, it can be very time-consuming to build and verify large models with standard commercial-off-the-shelf (COTS) software. Efficient simulation-model generation will allow the user to simplify and accelerate the process of producing correct and credible simulation models [117].
- A number of issues related to the design of manufacturing networks and their management, are still not tackled in a holistic integrated manner. The results of individual modules often contradict each other because they refer to not directly related manufacturing information and context (e.g. long term strategic scheduling vs. short term operational scheduling). The harmonisation, both on an input / output level and to the actual contents of information is often a mistreated issue that hinders the applicability of tools to real life manufacturing systems. Future work directions in this broad research field are outlined above. The pursuit for a smoother, more efficient, more rewarding and eco-friendly manufacturing is ongoing.

Concluding, it is obvious that enterprises are starting to adopt innovative tools and models deriving from virtual, smart and digital factory concepts for the design and planning of manufacturing networks and individual facilities. But, still many of these technologies are still in their infancy, expensive, complicated and hard to apply in real industrial contexts. Last but not least, the complexity of existing frameworks used in the design phases is increased and requires high skill and long processing time which, as a result, do not facilitate the use of crowdsourcing. Effort is made in order to create smart, intelligent and self-learning tools. The use of simulation in the framework of network design and planning is constantly evolving and spread. In conclusion, there is a significant evolution of technologies around manufacturing network design and planning but they are still undoubtedly a fertile field of research in view of the changing market, political, societal, technological and environmental changes.

## References

- [1] Mourtzis D, Doukas M. The evolution of manufacturing systems: From craftsmanship to the era of customisation. In Modrak V, Semanco P,

- editors. Design and Management of Lean Production Systems. IGI Global, ISBN13: 9781466650398, <http://www.igi-global.com/book/handbook-research-design-management-lean/84172/>.
- [2] ElMaraghy H, Schuh G, ElMaraghy W, Piller F, Schönsleben P, Tseng M, Bernard A. Product variety management. *CIRP Annals - Mfg Tech* 2013;62(2):629-652.
- [3] Chryssolouris G., Papakostas N. Dynamic Manufacturing Networks in a Globalized Economy. 8<sup>th</sup> International Conference on Digital Enterprise Technology - DET 2014. Keynote Presentation, March 25 - 28, 2014, Stuttgart, Germany, ISBN: 9783839606971.
- [4] Tolio T, Ceglarek D, ElMaraghy HA, Fischer A, Hu SJ, Laperrière L, Newman ST, Váncza J. SPECIES - Co-evolution of products, processes and production systems. *CIRP Annals - Mfg Tech* 2010;59(2):672-693.
- [5] Warren NA. Internet and Globalisation. In Gangopadhyay P, Chatterji M, editors. Economics of Globalisation. Ashgate, USA; 2005.
- [6] Oliver J, Houlihan JB, Logistics management - the present and the future. *Proceedings of 1986 BPICS Conference*; 1986. p. 91-99.
- [7] Wilding R. The supply chain complexity triangle: Uncertainty generation in the supply chain. *Int J Phy Distr & Log Mgmt* 1998;28(8):599-616.
- [8] Gereffi G. International trade and industrial upgrading in the apparel commodity chain. *J Int Econ* 1999;48(1):37-70.
- [9] Váncza J, Monostori L, Lutters D, Kumara SR, Tseng M, Valckenaers P, Van Brussel H. Cooperative and responsive manufacturing enterprises, *CIRP Annals - Mfg Tech* 2011;60(2):797-820.
- [10] Wiendahl HP, ElMaraghy HA, Nyhuis P, Záh MF, Wiendahl HH, Duffie N, Brieke M. Changeable Manufacturing - Classification, Design and Operation, *CIRP Annals - Mfg Tech* 2007;56(2):783-809.
- [11] Chryssolouris G. *Manufacturing Systems: Theory and Practice*. 2<sup>nd</sup> ed. New York: Springer-Verlag; 2006.
- [12] Tolio T, Urgo M. A Rolling Horizon Approach to Plan Outsourcing in Manufacturing-to-Order Environments Affected by Uncertainty, *CIRP Annals - Mfg Tech* 2007;56(1):487-490.
- [13] Hu SJ, Ko J, Weyand L, ElMaraghy HA, Kien TK, Koren Y, Bley H, Chryssolouris G, Nasr N, Shpitalni M. Assembly system design and operations for product variety, *CIRP Annals - Mfg Tech* 2011;60(2):715-733.
- [14] Chui M, Loffler M, Roberts R. *The Internet of Things*. McKinsey Quarterly, 2010.
- [15] Monostori L, Váncza J, Kumara SRT. Agent-Based Systems for Manufacturing, *CIRP Annals - Mfg Tech* 2006;55(2):697-720.
- [16] Gunasekaran A, Ngai EWT. The future of operations management: An outlook and analysis. *Int J of Prod Econ* 2012;135(2):687-701.
- [17] Shah R, Ward PT. Defining and developing measures of lean production. *J Oper Mgmt* 2007;25(4):785-805.
- [18] Prince J, Kay JM. Combining lean and agile characteristics: Creation of virtual groups by enhanced production flow analysis. *Int J Prod Econ* 2003;85(3):305-318.
- [19] Pine BJ. *Mass Customization: The New Frontier in Business Competition*. Boston, MA: Harvard Business School Press; 1992.
- [20] Da Silveira G, Borenstein D, Fogliatto FS. Mass customization: Literature review and research directions. *Int J Prod Econ* 2001;72(1):1-13.
- [21] Fogliatto FS, Da Silveira G, Borenstein D. The mass customization decade: an updated review of the literature. *Int J Prod Econ* 2012;138(1):14-25.
- [22] Montreuil B, Poulin M. Demand and supply network design scope for personalized manufacturing. *Prod Plan Con* 2005;16(15):454-469.
- [23] Chandler AD. *Scale and Scope*. Cambridge, MA: Harvard University Press; 1990.
- [24] Hounshell A. *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States*. Baltimore, MD: Johns Hopkins University Press; 1984.
- [25] Piller FT, Mösllein KM. From economies of scale towards economies of customer interaction: Value creation in mass customization based electronic commerce. 15<sup>th</sup> Bled Electronic Commerce Conference, TU München; 2002. p. 214-228.
- [26] Thirumalai S, Sinha K. Customization of the online purchase process in electronic retailing and customer satisfaction: An online field study, *J Oper Mgmt* 2011;29:477-487.

- [27] Ueda K, Takenaka T, Vánca J, Monostori L. Value creation and decision-making in sustainable society, *CIRP Annals – Mfg Tech* 2009;58(2):681-700.
- [28] Mourtzis D, Doukas M, Psarommatis F. A multi-criteria evaluation of centralized and decentralized production networks in a highly customer-driven environment, *CIRP Annals - Mfg Tech* 2012;61(1):427-430.
- [29] Koren Y. *The Global Manufacturing Revolution*. 2<sup>nd</sup> ed. Hoboken, New Jersey: John Wiley & Sons Inc; 2009.
- [30] Holweg M, Disney SM, Hines P, Naim MM. Towards responsive vehicle supply: a simulation-based investigation into automotive scheduling systems, *J Oper Mgmt* 2005;23(5):507-530.
- [31] Elias S. *New Car Buyer Behaviour*. 3DayCar Research Report. Cardiff Business School; 2002.
- [32] Knight K. Survey: 89% of consumers prefer online shopping. Bizreport. [http://www.bizreport.com/2007/12/survey\\_89\\_of\\_consumers\\_prefer\\_online\\_shopping.html](http://www.bizreport.com/2007/12/survey_89_of_consumers_prefer_online_shopping.html); 2007.
- [33] Helms M, Ahmadi M, Jih W, Ettkin L. Technologies in support of mass customization strategy: Exploring the linkages between e-commerce and knowledge management. *Comp in Ind* 2008;59(4):351-363.
- [34] Franke N, Keinz P, Schreier M. Complementing Mass Customization Toolkits with User Communities: How Peer Input Improves Customer Self-Design. *J Prod Inn Mgmt* 2008;25(6):546-559.
- [35] Feldmann K, Rottbauer H, Roth N. Relevance of Assembly in Global Manufacturing. *CIRP Annals – Mfg Tech* 1996;45(2):545-552.
- [36] Chen L, Song Z, Feng L. Internet-Enabled Real-Time Collaborative Assembly Modelling via an E-Assembly System: Status and Promise. *Comp Aid Des* 2004;36(9):835-847.
- [37] Janardanan VK, Adithan M, Radhakrishnan P. Collaborative Product Structure Management for Assembly Modelling. *Comp Ind* 2008;59(8):820-832.
- [38] Mourtzis D, Doukas M, Psarommatis F. Design and Operation of Manufacturing Networks for Mass Customisation. *CIRP Annals – Mfg Tech* 2013;63(1):467-470.
- [39] Cunha PF, Ferreira PS, Macedo P. Performance evaluation within cooperate networked production enterprises. *Int J Comp Int Mfg* 2008;21(2):174-179.
- [40] Weber CA, Current JR, Benton WC. Vendor selection criteria and methods. *Eur J Oper Res* 1991;50(1):2-18.
- [41] Wu C, Barnes D. A literature review of decision-making models and approaches for partner selection in agile supply chains. *J Pur Sup Mgmt* 2011;17(4):256-274.
- [42] Mourtzis D. Internet based collaboration in the manufacturing supply chain, *CIRP J Mfg Sci Tech* 2011;4(3):296-304.
- [43] Chase RB. *Production and Operations Management: Manufacturing and Services*. Irwin McGraw Hill; 1998.
- [44] Li X, Wang Q. Coordination mechanisms of supply chain systems, *Eur J Oper Res* 2007;179(1):1-16.
- [45] Windt K, Böse F, Philipp T. Autonomy in production logistics: Identification, characterisation and application, *Rob Comp Int Mfg* 2008;24(4):572-578.
- [46] Nyhuis P, von Cieminski G, Fischer A, Feldmann K. Applying Simulation and Analytical Models for Logistic Performance Prediction. *CIRP Annals – Mfg Tech* 2005;54(1):417-422.
- [47] Jain AS, Meeran S. Deterministic job-shop scheduling: Past, present and future. *Eur J Oper Res* 1999;113(2):390-434.
- [48] Wu C, Barnes D, Rosenberg D, Luo X. An analytic network process-mixed integer multi-objective programming model for partner selection in agile supply chains. *Prod Pl & Cont: Mgmt Oper* 2009;20(3):254-275.
- [49] Liang TF, Cheng HW. Application of fuzzy sets to manufacturing / distribution planning decisions with multi-product and multi-time period in supply chains. *Exp Sys App: Int J* 2009;36:3367-3377.
- [50] Tan PS, Lee S, Goh AES. Multi-criteria decision techniques for context-aware B2B collaboration in supply chains. *Dec Sup Sys* 2012;52(4):779-789.
- [51] Zhang L, You X, Jiao J, Helo P. Supply chain configuration with co-ordinated product, process and logistics decisions: an approach based on Petri nets. *Int J Prod Res* 2008;47(23):6681-6706.
- [52] Yao J, Liu L. Optimization analysis of supply chain scheduling in mass customization, *Int J Prod Econ* 2009;117(1):197-211.
- [53] Mula J, Peidro D, Mandronero MD, Vicens E., *Mathematical programming models for supply chain production and transport planning*, *Eur J Oper Res* 2010;204:377-390.
- [54] Kanda AA, Deshmukh SG. Supply chain coordination: Perspectives, empirical studies and research directions. *Int J Prod Econ* 2008;15(2):316-335.
- [55] Suh NP. *Complexity: Theory and Applications*. Oxford University Press, USA, ISBN: 9780195178760; 2005.
- [56] Shannon CE, Weaver W. *A Mathematical Theory of Communication*. 1<sup>st</sup> ed. Urbana: University of Illinois, Press; 1949.
- [57] Peters K, Worbs J, Parlitz U, Wiendahl HP. Manufacturing systems with restricted buffer sizes. In: Radons G, Naugebauer R, editors. *Nonlinear Dynamics of Production Processes*. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA; 2004. p. 39-54.
- [58] Papakostas N, Efthymiou K, Mourtzis D, Chryssolouris G. Modelling the complexity of manufacturing systems using non-linear dynamics approaches, *CIRP Annals – Mfg Tech* 2009;58(1):437-440.
- [59] Vrabčić R, Butala P. Computational mechanics approach to managing complexity in manufacturing systems. *CIRP Annals - Mfg Tech* 2011;60(1):503-506.
- [60] ElMaraghy HA, Urbanic RJ. Modelling of manufacturing systems complexity, *CIRP Annals – Mfg Tech* 2003;52(1):363-366.
- [61] ElMaraghy HA, Kuzgunkaya O, Urbanic RJ. Manufacturing systems configuration complexity, *CIRP Annals – Mfg Tech* 2005;54(1):445-450.
- [62] Efthymiou K, Papakostas N, Mourtzis D, Chryssolouris G. Fluid Dynamics Analogy to Manufacturing Systems. 42<sup>nd</sup> CIRP Conference on Manufacturing Systems, Grenoble, France; 2009.
- [63] Duffie NA, Roy D, Shi L. Dynamic modelling of production networks of autonomous work systems with local capacity control, *CIRP Annals-Mfg Tech* 2008;57(1):463-466.
- [64] Perona M, Miragliotta G. Complexity management and supply chain performance assessment. A field study and a conceptual framework. *Int J Prod Econ* 2004;90(1):103-115.
- [65] ElMaraghy W, ElMaraghy H, Tomiyama T, Monostori L. Complexity in engineering design and manufacturing, *CIRP Annals-Mfg Tech* 2012;61(2):793-814.
- [66] Thomas GJ, Griffin PM. Coordinated supply chain management. *Eur J Oper Res* 1996;94:1-15.
- [67] Akçalı E, Çetinkaya S. Quantitative models for inventory and production planning in closed-loop supply chains. *Int J Prod Res* 2011;49(8):2373-2407.
- [68] Lanza G, Peters S. Integrated capacity planning over highly volatile horizons. *CIRP Annals – Mfg Tech* 2012;61(1):395-398.
- [69] Lödding H, Yu KW, Wiendahl HP. Decentralized WIP-oriented manufacturing control (DEWIP). *Prod Pl Cont: Mgmt Oper* 2003;14(1): 42-54.
- [70] Aloini D, Dulmin R, Mininno V. Modelling and assessing ERP project risks: A Petri Net approach. *Eur J Oper Res* 2012;220(2):484-495.
- [71] Mourtzis D, Papakostas N, Mavrikios D, Makris S, Alexopoulos K. The role of simulation in digital manufacturing-Applications and Outlook. *Int J Comp int Mfg* 2012; DOI:10.1080/0951192X.2013.800234.
- [72] Madapusi A, D'Souza D. The influence of ERP system implementation on the operational performance of an organisation. *Int J Inf Mgmt* 2012;32(1):24-34.
- [73] Salmeron J, Lopez C. A multicriteria approach for risks assessment in ERP maintenance. *J Sys Soft* 2010;83(10):1941-1953.
- [74] Yeh C, Xu Y. Managing critical success strategies for an enterprise resource planning project. *Eur J Oper Res* 2013;230(3):604-614.
- [75] Aloini D, Dulmin R, Mininno V. Risk assessment in ERP projects. *Information Systems* 2012;37(3):183-199.
- [76] Olhager J. Evolution of operations planning and control: from production to supply chains, *Int J of Prod Res*, 2013;51(23-24):6836-6843.
- [77] Panorama Consulting. *ERP Report*. Denver, Colorado: A Panorama Consulting Solutions Research Report; 2014.
- [78] Plossl GW. *Orlicky's Material Requirements Planning*. 3<sup>rd</sup> ed. McGraw-Hill; 2011.
- [79] Bielajew A. History of Monte Carlo. In: Seco J, Verhaegen F, editors. *Monte Carlo Techniques in Radiation Therapy*, Taylor and Francis; 2013.

- [80] Mourtzis D, Doukas M, Bernidakis D. Simulation in Manufacturing: Review and Challenges, 8<sup>th</sup> International Conference on Digital Enterprise Technology - DET 2014. March 25 – 28, 2014. Stuttgart, Germany; ISBN: 9783839606971.
- [81] Goldsman D, Nance R, Wilson J. A brief history of Simulation Revisited. Proceedings of the 2010 Winter Simulation Conference; 2010, p.567-574.
- [82] Nance R. A history of discrete event simulation programming languages. Proceeding HOPL-II The second ACM SIGPLAN conference on History of programming languages; 1993, p. 149-175.
- [83] Conway RW. Some tactical problems in digital simulation. *Mgmt Sci* 1963;10(1):47-61.
- [84] Nance R, Sargent R. Perspectives on the Evolution of Simulation. *Electrical Engineering and Computer Science*; 2002, Paper 100.
- [85] Rosen K. The history of medical simulation. *J Crit Care* 2008;23:157-166.
- [86] Lu SCY, Shpitalni M, Gadh R. Virtual and Augmented Reality Technologies for Product Realisation. *Annals of the CIRP Keynote Paper* 1999;48(2):471-494.
- [87] Dugal LF, Healy M, Tankenton S. *Supply Chain Management: A Challenge to Change*, Coopers & Lybrand Report; 1994.
- [88] Maropoulos P. Digital enterprise technology--defining perspectives and research priorities. *Int J of Comp Int Mgmt* 1994;16(7-8):467-478.
- [89] Komoto H, Tomiyama T, Silvester S, Brezet H. Analyzing supply chain robustness for OEMs from a life cycle perspective using life cycle simulation. *Int J Prod Econ* 2011;134:447-457.
- [90] Komoto H, Tomiyama T, Nagel M, Silvester S, Brezet H. A Multi-Objective Reconfiguration Method of Supply Chains through Discrete Event Simulation. Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing, *Eco Design* 2005, p. 320-325.
- [91] Grewal CS, Enns ST, Rogers P. 2010, Dynamic adjustment of replenishment parameters using optimum-seeking simulation. *Simulation Conference (WSC), Proceedings of the 2010 Winter*; 2005, p. 1797-1808.
- [92] Umeda S, Zhang F. A simulation modelling framework for supply chain system analysis. *Simulation Conference (WSC), Proceedings of the 2010 Winter*; 2010, p. 2011-2022.
- [93] Hennies T, Reggelin T, Tolujew J, Piccut PA. Mesoscopic supply chain simulation. *J Comp Sci* Available online 24 September 2013.
- [94] Bughin J, Chui M, Manyika CJ. Big data, and smart assets: ten technology-enabled business trends to watch. *McKinsey Quarterly*, McKinsey Global Institute, August 2010.
- [95] Xu X. From cloud computing to cloud manufacturing. *Rob Comp Int Mfg* 2012;28(1): 75-86.
- [96] Mell P, Grance T. Perspectives on cloud computing and standards. National Institute of Standards and Technology (NIST). *Information Technology Laboratory*; 2009.
- [97] Mourtzis D, Doukas M, Vlachou K, Xanthopoulos N. Machine availability monitoring for adaptive holistic scheduling: A conceptual framework for mass customisation. 8<sup>th</sup> International Conference on Digital Enterprise Technology - DET 2014. March 25-28, 2014, Stuttgart, Germany, ISBN: 9783839606971.
- [98] CAPP-4-SMEs. Collaborative and Adaptive Process Planning for Sustainable Manufacturing Environments – CAPP4SMEs. EC Funded Project, 7<sup>th</sup> Framework Programme. Grant Agreement No.: 314024.
- [99] Tapoglou N, Mehnen J, Doukas M, Mourtzis D. Optimal tool-path programming based on real-time machine monitoring using IEC 61499 function blocks: A case study for face milling. 8<sup>th</sup> ASME 2014 International Manufacturing Science and Engineering Conference; June 9-13, 2014, Detroit, Michigan.
- [100] Valilai OF, Houshmand M. A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm. *Rob Comp Int Mfg* 2013;29(1):110-127.
- [101] Wu D, Thames JL, Rosen DW, Schaefer D. Towards a Cloud-Based Design and Manufacturing Paradigm: Looking Backward, Looking Forward. 32<sup>nd</sup> Computers and Information in Engineering Conference ASME Proceedings, Chicago, Illinois, USA, August 12-15, 2012, p. 315-328.
- [102] European Parliament. Unleashing the potential of cloud computing in Europe. European Parliament, Committee on Industry, Research and Energy (ITRE). Mini-hearing 30 May 2013.
- [103] Lewis G. Basics about Cloud Computing. Software Engineering Institute, Carnegie Mellon University: Pittsburgh; September 2010.
- [104] Tao F, Zhang L, Venkatesh VC, Luo Y, Cheng Y. Cloud manufacturing: A computing and service-oriented manufacturing model. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 2011;225(10):1969-1976.
- [105] Su CJ. Effective Mobile Assets Management System Using RFID and ERP Technology. WRI International Conference on Communications and Mobile Computing 2009; p. 147-151.
- [106] Schabel S. ERP - Mobile Computing. Thesis, Wien: Universität, Wien, 2009.
- [107] Chan E, Yu KM. A concurrency control model for PDM systems, *Comp Ind* 2007;58(8-9):823-831.
- [108] Nee AYC, Ong SK, Chryssolouris G, Mourtzis D. Augmented reality applications in design and manufacturing. *CIRP Annals-Mfg Tech* 2012;61:657-679.
- [109] Wang L. Machine availability monitoring and machining process planning towards Cloud manufacturing. *CIRP J Mfg Sci Tech* 2013;6(4):263-273.
- [110] Brondi C, Carpanzano E. A modular framework for the LCA-based simulation of production systems, *CIRP J Mfg Sci Tech* 2011;4(3):305-312.
- [111] Sihn W, Pfeffer M. A method for a comprehensive value stream evaluation, *CIRP Annals – Mfg Tech* 2013;62(1):427-430.
- [112] Dignum V. An Overview of Agents in Knowledge Management. In: Umeda M, editors. *Proceedings of INAP-05*: Springer; 2006. p. 175-189.
- [113] Mourtzis D, Doukas M. Knowledge capturing and reuse to support mass customisation: A case study from the mould making industry, *Procedia CIRP*. 24<sup>th</sup> CIRP Design Conference 2014. Milan, Italy 2014.
- [114] Valckenaers P, Brussel H, Verstraete P, Hadel, GB. Schedule execution in autonomic manufacturing execution systems, *J Mfg Sys* 2007;26(2):75-84.
- [115] Ramanathan U. Performance of supply chain collaboration – A simulation study. *Exp Sys App* 2014;41(1): 210-220.
- [116] Shariatzadeh N, Sivard G, Chen D. Software Evaluation Criteria for Rapid Factory Layout Planning, Design and Simulation, *Procedia CIRP* 2012;3:299-304.
- [117] Lee JY, Kang HS, Kim GY, Noh SD. Concurrent material flow analysis by P3R-driven modelling and simulation in PLM, *Comp Ind* 2012;63(5):513-527.
- [118] Xu HC, Xu XF, HE T. Research on Transformation Engineering BOM into Manufacturing BOM Based on BOP. *App Mech Mat* 2007;10-12:99-103.
- [119] Eppinger SD, Browning TR. *Design Structure Matrix Methods and Applications*. ISBN: 9780262017527; 2012.
- [120] Schuh G, Rozenfeld H, Assmus D, Zancul E. Process oriented framework to support PLM implementation. *Comp Ind* 2008;59(2-3):210-218.
- [121] Huth A, Cebula J. *The Basics of Cloud Computing*. US-CERT, United States Computer Emergency Readiness Team 2011, Produced by Carnegie Mellon University.
- [122] TechNavio Analysis. *Global Cloud Security Software Market*. 2011. Accessed online on: 20-05-2014, URL: <http://www.technavio.com/report/global-cloud-security-software-market-2010-2014>.
- [123] MindCommerce. *Mobile Value-added Services (VAS) in the Cloud: Security Challenges, Market Opportunities and Forecasts 2013 – 2018*. Accessed online on: 20-05-2014. URL: [http://www.mindcommerce.com/Publications/MVAS\\_Cloud\\_Security\\_2013-2018.php](http://www.mindcommerce.com/Publications/MVAS_Cloud_Security_2013-2018.php).