Logist. Res. (2016) 9:2
DOI 10.1007/s12159-015-0129-0

ORIGINAL PAPER

Challenges and future perspectives for the life cycle of manufacturing networks in the mass customisation era

D. Mourtzis[1]

Received: 10 June 2015 / Accepted: 21 December 2015 / Published online: 5 January 2016

Abstract Manufacturers and service providers are called to design, plan, and operate globalised manufacturing networks, addressing to challenges of increasing complexity in all aspects of product and production life cycle. These factors, caused primarily by the increasing demand for product variety and shortened life cycles, generate a number of issues related to the life cycle of manufacturing systems and networks. Focusing on the aspects that affect manufacturing network performance, this work reviews the exiting literature around the design, planning, and control of manufacturing networks in the era of mass customisation and personalisation. The considered life cycle aspects include supplier selection, initial manufacturing network design, supply chain coordination, complexity, logistics management, inventory and capacity planning and management, lot sizing, enterprise resource planning, customer relationship management, and supply chain control. Based on this review and in correlation with the view of the manufacturing networks and facilities of the future, directions for the development of methods and tools to satisfy product–service customisation and personalisation are promoted.

Keywords Manufacturing systems and networks · Design · Planning · Mass customisation

This article is part of a focus collection on "Robust Manufacturing Control: Robustness and Resilience in Global Manufacturing Networks".

✉ D. Mourtzis
mourtzis@lms.mech.upatras.gr

1 Laboratory for Manufacturing Systems and Automation, University of Patras, 26500 Patras, Greece

1 Introduction

Mass production (MP) has been the established manufacturing paradigm for nearly a century. MP initially answered to the need of the continuously increasing population around the globe, with a gradual improvement in its living standards, especially in the developed world, for goods and commodities. However, since the 1980s and with the beginning of the new millennium, a saturation of the market towards mass produced products is observed. In 2006, Chryssolouris states that: "It is increasingly evident that the era of MP is being replaced by the era of market niches. The key to creating products that can meet the demands of a diversified customer base, is a short development cycle yielding low cost and high quality goods in sufficient quantity to meet demand" [1]. Currently, the need for increased product variety is intensifying, and customers in many market segments request truly unique products, tailored to their individual taste. Companies are striving to offer product variety while trying to produce more with less [2] (i.e. maximise their output while minimising the use of materials and environmental footprint), while the landscape that they must operate in, inflicted by the economic recession, has become more complex and dynamic than ever.

In the mass customisation (MC) paradigm, the establishment of which is still an ongoing process, instead of treating customers merely as product buyers, a producer must consider them as integrated entities in the product design and development cycle. In this customer-driven environment that is shifting towards online purchases and market globalisation, the underlying manufacturing systems and chains are heavily affected. Owing to its multidisciplinary nature, the manufacturing domain in general lacks of unified solution approaches [3]. The management of the co-evolution of product, process and production on a strategic and operational level is a huge challenge. Market globalisation broadens the target audience of a product, while at the same time it constitutes supply strategies and logistics' more difficult to manage. Adding to that, the Internet, one of the primary enablers of globalisation, allowed online customisation and purchasing, leading to new disruptive purchasing models. In their turn, these models affected long-established businesses that could not form an online presence fast and succumbed to the competition. Moreover, the economic recession highlighted the need for quick adaptation to demand; companies that could not adapt to the new requirements suffered economic losses and their viability was challenged. Simultaneously, the decreasing product costs and the increase in purchasing power in developing countries generated new markets and destabilised demand. Finally, the emergence of new materials, new forms of production, and key enabling technologies constitute new diversified product features and processes feasible, as well as they allow the interconnection between ICT systems, humans, and engineering/manufacturing phases.

It becomes apparent that manufacturers and service providers are presented with numerous external and internal drivers and challenges [4] that have a visible impact on the smooth operation of the entire value-adding network down to each individual manufacturing facility [5]. A root cause for these problems is that while the MC paradigm proposes a set of practices and solutions for tackling these issues, its practical implementation is still considered as work in progress in terms of effectiveness of coordination and collaboration between stakeholders, design and planning of networks and facilities, and execution and control efficiency [6]. An enabling solution for realising a cost-effective implementation of MC is to properly configure easily adaptable manufacturing networks, which are capable to handle the complexity and disturbances that modern production requirements inflict [7]. Support systems for the design, planning, and control with inherent robustness are necessary in order for companies to withstand the antagonism through sustainable practices. Technology-based business approaches comprise a major enabler for the realisation of robust manufacturing systems and networks that offer high value-added, user-oriented products and services. These qualities are critical for companies in order to master variety and maintain their viability [8]. Significant work has been conducted on this field, yet a focused review of the literature regarding the influence of MC practices on different aspects of the manufacturing network life cycle is missing. In particular, the lack of dedicated reviews on the challenging issues of design, planning, and operation of manufacturing networks in the framework of MC forms the motivation for conducting this work [9].

Towards bridging this gap in academic approaches, this work reviews the existing literature related to the basic aspects of a manufacturing network from its design, planning, and control life cycle perspectives within the general MC landscape, targeting to the understanding of the current situation and identification of future developments. For the scope of the paper, areas of supplier selection, initial manufacturing network design, supply chain coordination, complexity, logistics management, inventory and capacity planning and management, lot sizing, enterprise resource planning (ERP), customer relationship management (CRM), and supply chain control are reviewed. The purpose is to establish an overview of the current status of academic research and pinpoint the challenges that have yet to be addressed by academic work. Departing from that, major drivers and enabling technologies are identified, as well as concepts that can lead to a more sustainable implementation of MC are proposed.

The review is based on structured search in academic journals and books, which were retrieved primarily from Scopus and Google Scholar databases, using as keywords the main fields of interest of the study, namely: evolution of manufacturing paradigms, issues in MC and personalisation environments, the role of simulation for manufacturing, methods and technologies related to product and production complexity, and 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 2015, with only a few notable exceptions. Sciences that were considered in the search were: engineering, management, business, and mathematics. The review was carried out in three stages: (1) search in scientific databases with relevant keywords, (2) identification of the relevant papers after reading their abstract, and (3) full-text reading and grouping into research topics. Indicatively, the frequency of results from a search with the keywords "mass customisation" or "product personalisation" in the abstract, title, and keywords of the article as obtained by the Scopus database is depicted in Fig. 1.

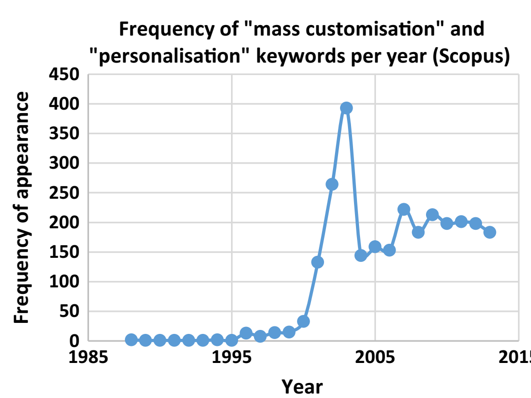


Fig. 1 Frequency of appearance of the keywords "mass customisation" and "personalisation" in the abstract, title, and keywords of the article

The above figure also visualises the increase of interest on these topics by the scientific community, and the establishment of MC as a distinct field of research. The trend resembles a typical hype cycle. In the beginning, the abstract concept of MC is born from the realisation that product variety is increasing. Then, key enabling technologies, such as the rise of the Internet, web-based collaboration means, and flexible manufacturing systems act as a trigger in the spread of MC, quickly reaching a peak during late 1990s and early 2000s. Until then, most studies are concerned with management and strategic issues of MC, failing to address critical MC implementation issues. Afterwards, researchers realised that a series of sub-problems ought to be tackled first, leading to research indirectly associated with MC (e.g. investigation of product family modelling techniques). Nevertheless, MC is here to stay, therefore, research interest on complete MC solutions starts appearing after 2005 and continues up to the current date.

The rest of the paper is structured as follows. Section 2 presents the evolution of manufacturing paradigms and discusses the recent shift towards customer-centred manufacturing. Section 3 performs a literature review on major topics related to the life cycle of manufacturing networks, together with the latest advances in ICT for supporting the design, planning, and control of manufacturing networks. Section 4 summarises the challenges that need to be addressed, aided by a generic view of the manufacturing landscape of the near future. Finally, Sect. 5 concludes the paper.

2 Evolution of manufacturing and current challenges

2.1 Evolution of manufacturing paradigms

Over time, manufacturing paradigms, driven by the pressure of the environment in which they operate, change in character and evolve in patterns (Fig. 2). The various patterns witnessed up to now can be roughly correlated to movements between three stages: (1) craft shops that employ skilled artisans, (2) long-linked industrial systems using rigid automation, and (3) post-industrial enterprises characterised by flexible resources and information intensive intellectual work [10]. Prevailing manufacturing paradigms are, in chronological order of appearance, the following: 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 [11].

By studying these notable transitions, which are attributed to the pressure applied by social needs, political factors, and advances in technology, it is noticeable that 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 [12]. Factory systems replaced craft modes of production as firms learned how to rationalise and product designs as well as standardise production itself [13]. 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 economic, manufacturing, and design concepts, has been a shift from simple economies of scale, as in the conventional MP of a limited number of products, to economies of scope and customer integration [14]. It is clear that MP factories or their analogues 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. A categorisation of the different production concepts based on the indicators system reconfigurability, demand volatility, and product complexity is depicted in Fig. 3.

Today, issues introduced by the shift of business models towards online purchasing and customisation [15] must be tackled in cost-efficient and sustainable ways in order for companies to maintain their competitiveness and create value [16]. To respond to consumer demand for higher product variety, manufacturers started to offer increased numbers of product "options" or variants of their standard product [17]. Therefore, practice nowadays focuses on strategies and methods for managing product, process, and production systems development that are capable of supporting product variety, adaptability, and leanness, built upon the paradigms of MC and product personalisation. The currently widespread MC is defined as a paradigm for "developing, producing, marketing and delivering affordable goods, and services with enough variety and

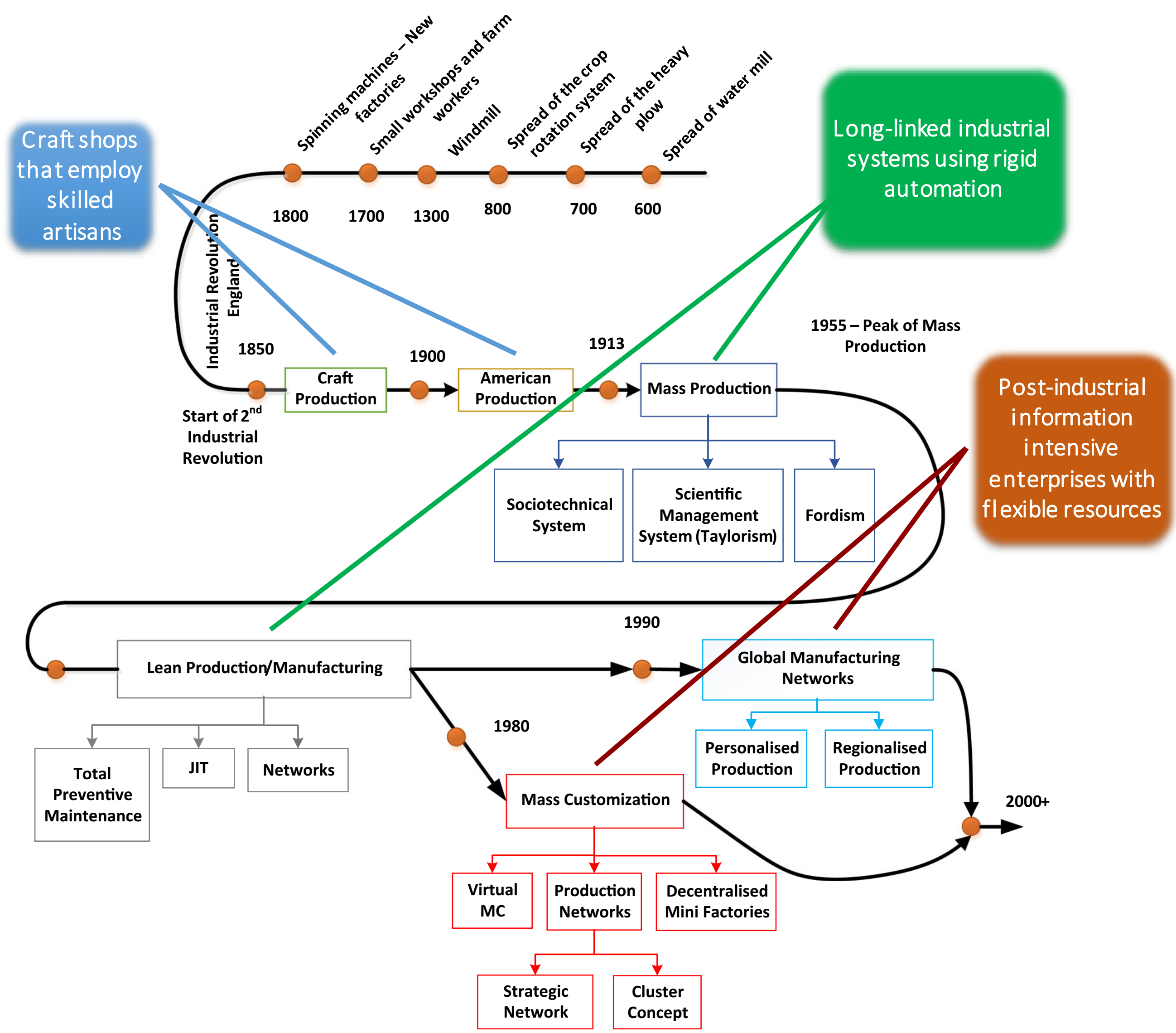


Fig. 2 Evolution of manufacturing paradigms (adapted from [11])

customisation that nearly everyone finds exactly what they want" [17]. This is achieved mostly through modularised product/service design, flexible processes, and integration between supply chain members [18, 19]. 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 [20]. At the same time, however, MC must achieve economies of scale, in a degree compared to that of MP, 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 customer integration in order to produce designs that the customers really want [14]. On the other hand, personalised production aims to please individual customer needs through the direct integration of the customer in the design of products. The major differences between the prominent paradigms of MP, MC, and personalisation in terms of goals, customer involvement, production system, and product structure are depicted in Fig. 4.

A research conducted in the UK related to automotive products revealed that 61 % of the customers wanted their vehicle to be delivered within 14 days [21], whereas consumers from North America responded that they could wait no longer than 3 weeks for their car, even if it is custom built [22]. Such studies point out the importance of responsiveness and pro-activeness for manufacturers in product and production design.

During the last 15 years, the number of online purchases has increased and recent surveys show that 89 % of the buyers prefer shopping online to in-store shopping [23]. Web-based and e-commerce systems have been

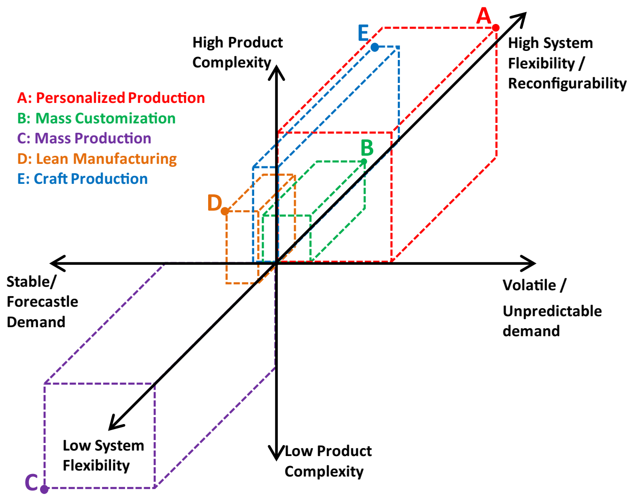


Fig. 3 Characterisation of production paradigms based on demand structure, product complexity, and product flexibility

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

Fig. 4 Differences between production paradigms (adapted from [20])

implemented and have proved to be very effective in capturing the pulse of the market [24]. 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 [25]. 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 [26] and web-based collaboration systems [27], the research in this area needs to be expanded in order to provide tools for assembly representation and product variant customisation. An additional constraint is that globalised design and manufacturing often require the variants for local markets to be generated by regional design teams, which use different assembly software and source parts from different supply bases [20]. 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 life cycle. It can be realised during design, assembly, at the stage of sales and distribution, and through adjustments at the usage phase. Moreover, variety can be realised during the fabrication process, e.g. through rapid prototyping [28].

It should finally be noted that naturally, even if the trends dictate a shift towards personalised product requirements, it should always be considered that forms of production such as MP 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.

2.2 Globalisation

Globalisation in manufacturing activities, apart from its apparent advantages, introduces a set of challenges. On the one hand, a globalised market offers opportunities for expanding the sphere of influence of a company, by widening its customer base and production capacity. Information and communication technologies (ICT) and the Internet have played a significant role to that [29]. 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 laboratories: when investigating the match between actual call off and the actual forecast, they estimated that supply and demand were in equilibrium for only 35 min in the period between 1976 and 1986 [30, 31]. Enterprises started locating their main production facilities in countries with favourable legislation and low cost of human labour [32]; 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 behaviours. Thus, manufacturing networks need to properly coordinate, collaborate, and communicate in order to survive [33].

On a manufacturing facility level, the impact of supply chain uncertainties and market fluctuations is also considerable. The design and engineering analysis of a complex manufacturing system is a devious task, and the operation of the systems becomes even harder when flexibility and reconfigurability parameters must be incorporated [34].

The process is iterative and can be separated into smaller tasks of manageable complexity. Resource requirements, resource layout, material flow, and capacity planning are some of these tasks [1], which even after decomposition and relaxation remain challenging [35]. In particular, in the context of production for MC 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 challenging, leaving ample room for improvement in order for the inconsistencies between process planning and line balancing to be minimised [20].

From a technological perspective, the increased penetration of ICT in all aspects of product and production life cycles enables a ubiquitous environment for the acquisition, processing, and distribution of information, which is especially beneficial for a globalised paradigm. With the introduction of concepts like cyber physical systems (CPS) and Internet of things (IoT) in manufacturing [36], 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 [37].

3 Manufacturing networks life cycle and mass customisation

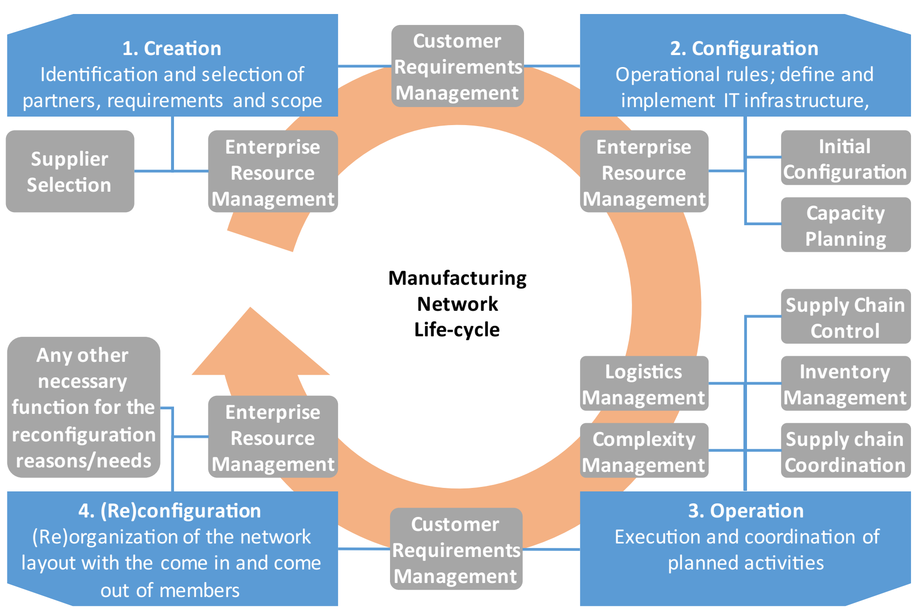
In this section, the recent advances and the challenges presented during the life cycle of a manufacturing network are discussed. A typical modern manufacturing network is composed of cooperating original equipment manufacturer (OEM) plants, suppliers, distribution centres, and dealers that produce and deliver final products to the market [38]. The topics discussed include supplier selection, supply chain coordination, initial network configuration, manufacturing network complexity, inventory management, capacity planning, warehousing, lot sizing, ICT support tools, and dynamic process planning, monitoring, and control. These topics are in line with the life cycle phases of a manufacturing network as reported in [39] (Fig. 5).

3.1 Supplier selection

The building blocks of any manufacturing network are the cooperating companies. The significance of the selection of these stakeholders (supplier, vendors) has been indicated as early as in 1966 as stressed in [40] and is known as the supplier selection problem. This decision-making problem is highly challenging since it goes beyond simple comparison of component prices from different suppliers. It is often decomposed 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 supplier selection in agile manufacturing chains is included in [41]. In Fig. 6, the decomposition of the supplier selection problem into small more manageable problems is presented, together with indicative methods for solving these sub-problems.

The supplier selection problem becomes even more complicated in the era of MC since a certain level of adaptability and robustness is necessary when operating within a volatile and rapidly changing environment. The

Fig. 5 Manufacturing network life cycle



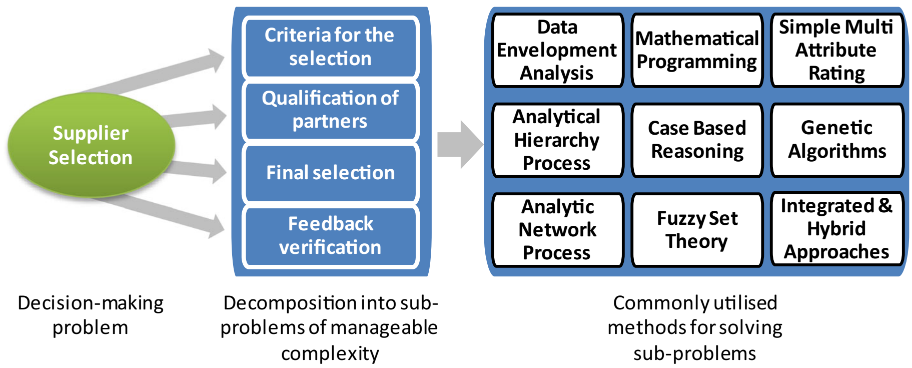


Fig. 6 Supplier selection problem, its decomposition into small more manageable problems, and indicative methods for solving them (adapted from [51])

most commonly used criteria in supplier selection studies include quality and performance [42]. However, when having to deal with unpredictability and fluctuating demand, which are common in MC, additional factors need to be considered such as management compatibility, transparency of operations, strategic direction, reliability, and agility [43]. While trying to adhere to eco-friendliness directives, frameworks like the one proposed in [44] incorporate environmental footprint criteria to green supply chain design. Moreover, several other criteria may be relevant according to the design and planning objectives of a niche supply chain, which could be identified using data mining methods [45].

The Internet and web-based platforms are used in recent years in order to counterbalance uncertainty, monitor altering parameters (e.g. weather in supply routes), and proactively adapt to changes [46]. Moreover, several proposed supplier selection models incorporate the relative importance of the supplier selection factors depending on the types of targeted MC implementation, e.g. for the component-sharing modularity type of MC, the requirements for selecting suppliers would not be the same as the component-sweeping modularity implementation type [47]. Like in the case of a stable low variety production, the analytic hierarchy process (AHP) is commonly used as a means to solve the multi-criteria decision-making problem of supplier selection. Incorporating uncertain information about the real world, essentially extending the Dempster–Shafer theory, the authors in [48] propose the D-AHP method for solving the supplier selection problem. The suggested D numbers preference relation encapsulates the advantages of fuzziness and handles possible incomplete and imprecise information, which is common in human-driven systems such as supply chains. Similarly, a combined analytic hierarchy process—quality function deployment (AHP–QFD) framework is described by [49] that handles uncertain information, selects suppliers, and allocates orders to them. A multi-criteria decision-making method to support the identification of business-to-business (B2B) collaboration schemes, especially for supplier selection is proposed in [50].

3.2 Supply chain coordination

The literature on organisational knowledge creation points out that “coordination” plays an important role in combining knowledge from stakeholders [52], while it also mediates the relationship between product modularity and MC [53]. A report on coordination mechanisms for supply chains was compiled in [54].

Concerning coordination in supply chains, in general, two topologies are studied, namely the centralised and the decentralised one [11] (Fig. 7). In the first, the coordination 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 decentralised topology has been proven to improve the performance in the context of MC [38, 55]. A supply chain that is commissioned to provide a variety of customised products requires a total systems approach to managing the

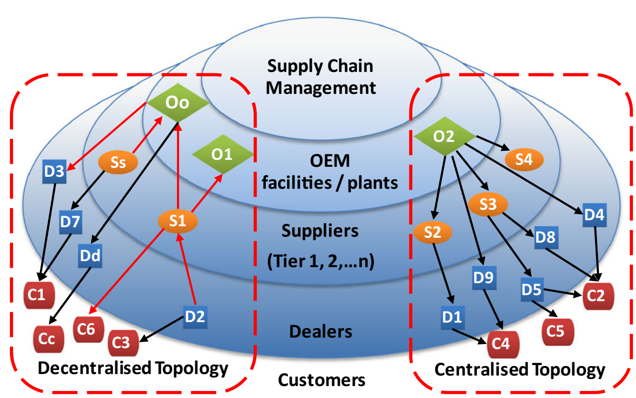


Fig. 7 Centralised and decentralised supply chain topologies. In a centralised topology, material and information move only downstream. In the decentralised one, material/information can be transferred both upstream and downstream to better serve customisation, personalisation, and/or regionalisation [6]

entire flow of information, materials, and services in fulfilling customer demand [56]. Further incentives have to be provided to the members, so as to entice their cooperation through the distribution of the benefits of the coordination for instance.

The need for adaptation to the new MC 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 [57]". However, regardless the topology, the alignment of the objectives of the different collaborating organisations in order to successfully carry out projects, optimise system performance, and achieve mutual profits is indispensable [58]. While an action plan suffices for the coordination of a centralised supply chain, it is inadequate with a decentralised one [59] since entities tend to exhibit opportunistic behaviour. Nevertheless, in terms of overall network performance, decentralised topologies have shown great benefits for serving the mass customisation paradigm [6, 7].

3.3 Initial manufacturing network configuration

The initial manufacturing network configuration must consider the long-term needs of cooperation and often determines its success. In a constantly changing environment, the configuration of the manufacturing network must be, therefore, flexible and adaptable to external forces. The problem has been extensively addressed in the literature using approaches classified in two main categories, namely approximation (artificial intelligence, evolutionary computation, genetic algorithms, tabu search, ant colony optimisation, simulated annealing, heuristics, etc.) and optimisation techniques (enumerative methods, Lagrangian relaxation, linear/nonlinear integer programming, decomposition methods, etc.) and their hybrids [60, 61] (Fig. 8).

Focusing on agile supply chains, a hybrid analytic network process mixed-integer programming model is proposed in [62] with uttermost aim the fast reaction to customer demands. Fuzzy mathematical programming techniques have been employed to address the planning problems for multi-period, multi-product supply chains [63]. A coloured Petri Nets approach for providing modelling support to the supply chain configuration issue is included in [64]. A dynamic optimisation mathematical model for multi-objective decision-making for manufacturing networks that operated in a MC environment is suggested in [65].

Still, the accuracy of planning ahead in longer horizons is restricted. The incorporation of unpredictable parameters in the configuration through a projection of the possible setting of the network in the future may lead to unsafe results.

3.4 Inventory management/capacity planning/lot sizing

Inventories are used by most companies as a buffer between supply chain stages to handle uncertainty and volatile demand. Prior to the 1990s, 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]. The basis for manufacturing and inventory planning was relatively safe forecasts. However, in the era of customisation the basis is actual orders and the pursuit is minimisation of inventories. These requirements constitute inventory management and capacity planning functions very important for a profitable MC implementation.

In complex distributed systems such as modern manufacturing companies with a global presence, the question of optimal dimensioning and positioning of inventory emerges as a challenging research question. Various strategies for inventory planning have been reported based on how

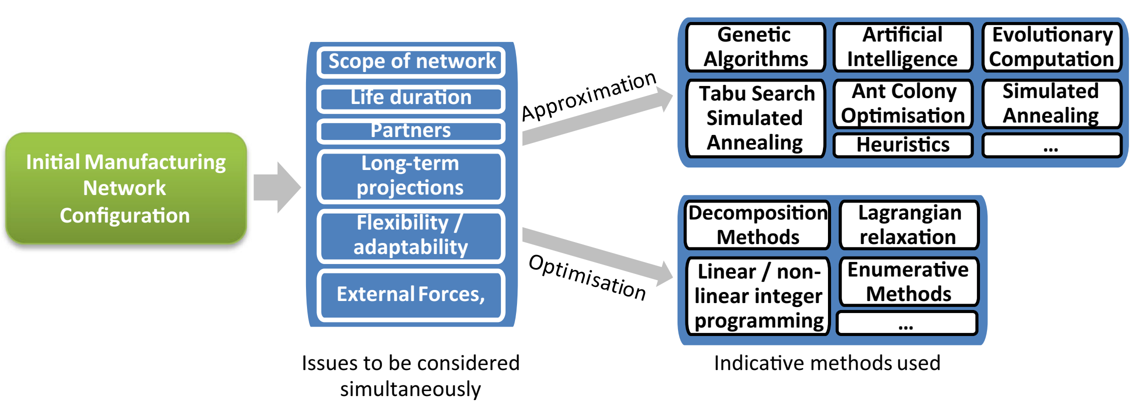


Fig. 8 Issues to be considered during the initial manufacturing network configuration and indicative methods used

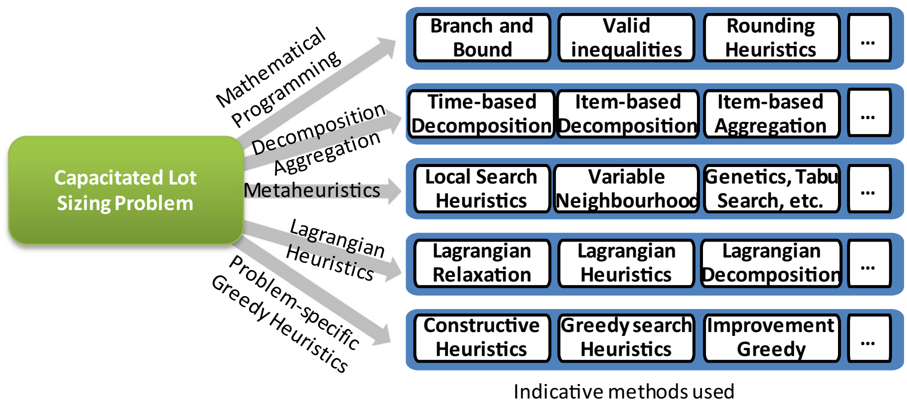


Fig. 9 Methods (indicative) used for solving the capacitated lot sizing problem (adapted from [70])

the underlying 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 optimisation models over volatile planning horizons exhibit high performance in the context of MC and personalisation [68]. The DEWIP (decentralised WIP) control mechanism was proposed in [69], focusing on establishing control loops between work centres for adjusting the WIP levels dynamically. Its performance was assessed against other well-accepted systems such as LOOR, Conwip, and Polca. Methods used for solving the capacitated lot sizing problem are indicatively shown in Fig. 9.

In particular, in just-in-time (JIT) environments, MC impacts the amount of inventory that needs to be carried by firms that supply many part variants to a JIT assembly line. In addition, the supply of parts is performed either on constant order cycles or more commonly under non-constant cycles [71]. The goal chasing heuristic, pioneered within the Toyota production system, seeks to minimise the variance between the actual number of units of a part required by the assembly line and the average demand rate on a product-unit-by-product-unit basis, while applying penalties for observed shortages or overages [72]. Of course, information sharing and partner coordination systems are a prerequisite for JIT procurements. For instance, DELL, which achieved a highly coordinated supply chain to respond to MC, communicated its inventory levels and replenishment needs on an hourly basis with its key suppliers and required from the latter to locate their facilities within a 15-min distance from DELL facilities [73]. Another consideration during inventory management is the type of postponement applied in a company. Studies have shown that postponement structures allow firms to meet the increased customisation demands with lower inventory levels in the case of time postponement (make-to-order), or with shorter lead times in the case of form postponement [74]. Also, an assemble-to-order process, a variation of form postponement, does not hold inventory of the finished product, while in form postponement, finished goods inventory for each distinct product at the product's respective point of customisation is kept [75]. An indicative example is given in the case of Hewlett Packard, where using form postponement, the company achieved the postponement of the final assembly of their DeskJet printers to their local distribution centres [76].

3.5 Logistics management

Logistics can play a crucial role in optimising the position of the customer order decoupling point and balance between demand satisfaction flexibility and productivity [77]. In a customer-centric environment, the supply chain logistics must be organised and operated in a responsive and at the same time cost-effective manner. Customisation of the bundle of product/services is often pushed downstream the supply chain logistics, and postponement strategies are utilised as an enabler for customisation [78]. Maintaining the product in a neutral and non-committed form for as long as possible, however, implicates the logistics process. Traditional logistics management systems and strategies need to be revisited in the context of customisation, since distribution activities play a key role in achieving high product variety, while remaining competitive. Most OEMs form strategic alliances with third-party logistic (TPLs) companies. The introduction of TPLs in the supply chain serves two purposes. First, it acts as a means of reducing the complexity of management for an OEM through shifting the responsibilities of transportation, and in many times customisation, to the TPLs [79]. Second, it extends the customisation capabilities as TPLs can actively implement postponement strategies [80]. Postponement strategies with logistics as an enabler are located at the bottom of Fig. 10 and can serve all types of customisation, from plain shipment to order up to extremes of engineer-to-order or personalisation.

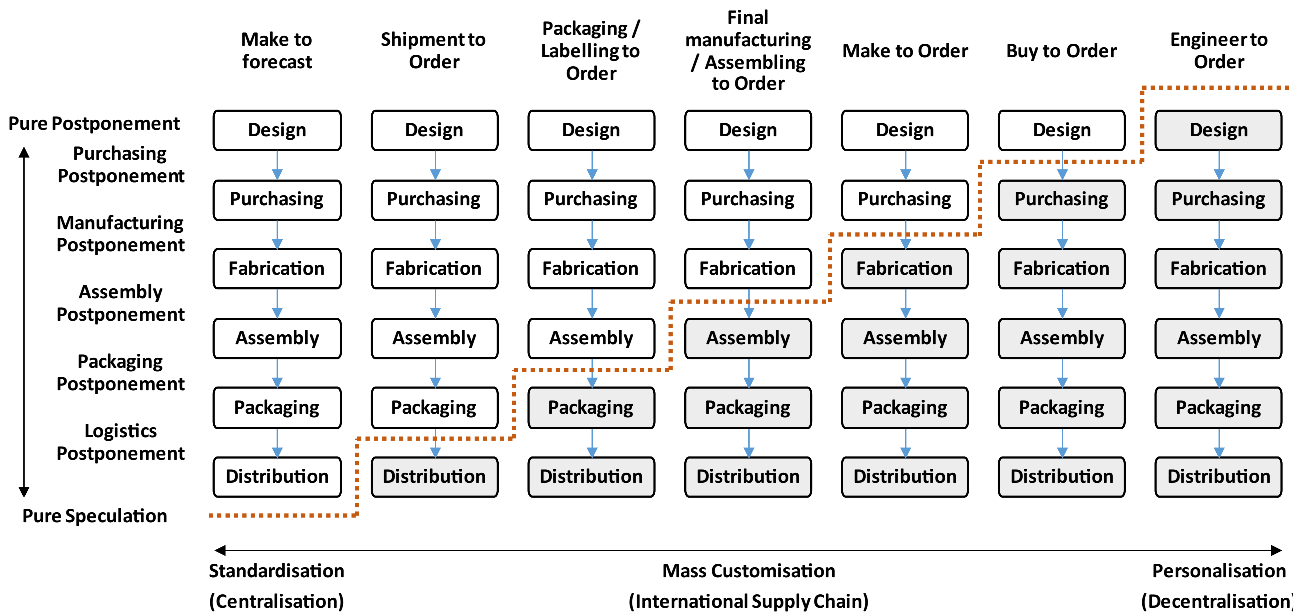


Fig. 10 Postponement strategies for different supply chain structures and logistics (adapted from [81])

Moreover, the management of logistics is a process inherently based on communication and collaboration. Developments of either function-specific or all-in-one ICT solutions targeted on logistics are analysed in [6, 82]. Tools for warehouse and transportation management, ERP, supply chain management (SCM), and information sharing are reported under the umbrella of e-logistics. The concept of virtual logistics is also proposed for separating the physical and digital aspects of logistics operations [83], having Internet as an enabling means to handle ownership and control of resources.

3.6 Supply chain control

The information transferred from one supply chain tier to the next in the form of orders is often distorted, a phenomenon known as the bullwhip effect. In particular, when customer demand is volatile such as the case is in MP, the bullwhip effect misguides upstream members of the supply chain in their inventory and production decisions [84]. Nevertheless, the performance of the supply chain is highly sensitive to the control laws used for its operation. The application of the wrong control policy may have as a result the amplification of variance instead on its minimisation. Dynamic modelling approaches have been proposed to manage supply chains, accounting for the flow of information and material, to capture the system dynamics [85]. Multi-agent approaches for modelling supply chain dynamics are proposed in [86]. Software components known as agents represent supply chain entities (supplier, dealers, etc.), their constituent control elements (e.g. inventory policy), and their interaction protocols (e.g. message types). The agent framework utilises a library of supply chain modelling components that have derived after analysis of several diversified supply chains. For instance, a novel oscillator analogy in presented in [87] for modelling the manufacturing systems dynamics. The proposed analogy considers a single degree of freedom mass vibrator and a production system, where the oscillation model has as input forces, while the manufacturing system has demand as excitation. The purpose is to use this simple oscillator analogy to predict demand fluctuations and take actions towards alignment.

Another necessity in supply chain control is the traceability of goods. Traceability methods, essential for perishable products and high-value shipments, exploit the radio frequency identification (RFID) technology during the last years [88, 89]. A traceability system that traces lots and activities is proposed by Bechini et al. [90]. The study examines the problem from a communication perspective, stressing the need to use neutral file formats and protocols such as XML (extended markup language) and SOAP (simple object access protocol) in such applications. The emerging technology of IoT can provide ubiquitous traceability solutions. Combining data collection methods based on wireless sensor network (WSN) with the IoT principles, the method proposed in [91] can support the traceability of goods in the food industry. In a similar concept, the role of an IoT infrastructure for order fulfilment in a collaborative warehousing environment is examined in [92]. The IoT infrastructure is based on RFID, ambient intelligence, and multi-agent system, and it integrates a bottom-up approach with decision support mechanisms such as self-organisation and negotiation protocols between agents based on a cooperation concept.

Supply chains formed for servicing customisation are more complex as structures and less predictable in their dynamic behaviour than stable traditional supply chains. Recent complexity studies deal with the emerging aspects of increasing complexity of manufacturing activities and the dynamic nature of supply chains [93]. 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 [38, 94]. A complete and comprehensive review of complexity in engineering design and manufacturing is presented in [95–97].

3.7 Simulation and ICT support systems for manufacturing networks life cycle

Robust and flexible ICT mechanisms are rendered necessary for improving performance in each of the previous life cycle aspects of supply chains and for bridging inter- and intra-enterprise collaboration environments. Digital enterprise technologies in general represent an established, new synthesis of technologies and systems for product and process development and life cycle management on a global basis [98] that brings many benefits to companies. For instance, the benefits offered by the adoption of virtual engineering through the life cycle of production are shown in Fig. 11 [99]. To manage the huge portfolio of products and variety, as well as tracking the expanding customer base, ERP and CRM suites are necessary tools. Additionally, cloud technology is already revolutionising core manufacturing aspects and provides ample benefits for supply chain and manufacturing network life cycle. Cloud technology and the IoT are major ICT trends that will reshape the way enterprises function in the years to come [100, 101].

3.8 Simulation for manufacturing network design

Literature on ICT-based systems for improving manufacturing networks is abundant and highlights the need for increased penetration of ICT systems in design, planning, and operation phases. A simulation-based method to model and optimise 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 life cycle costs [102]. 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 [103]. 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 [58]. Furthermore, the evaluation of the performance of automotive manufacturing networks under highly diversified product demand is succeeded through discrete event simulation models in [55] 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 utilising the MesoSim simulation software [104, 105].

Existing simulation-based approaches do not tackle the numerous issues of manufacturing network design in a holistic integrated manner. The results of individual modules used for tackling network design sub-problems 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), while harmonising the context among these modules is challenging. This shortcoming hinders the applicability of tools to real manufacturing systems as it reduces the trustworthiness of results to the eyes of the planner among other reasons.

3.9 Enterprise resource planning

An ERP system is a suite of integrated software applications used to manage transactions through company-wide

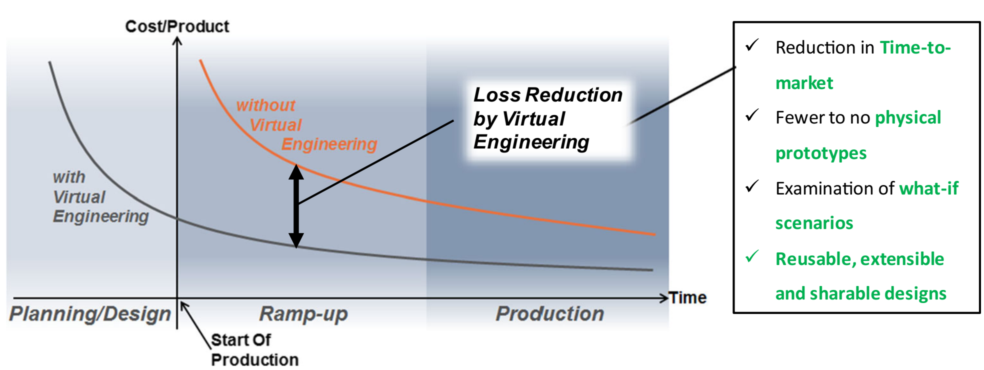


Fig. 11 Increased efficiency through virtual engineering approaches (adapted from [99])

business processes, by using a common database, standard procedures, and data sharing between and within functional areas [106]. Such ICT systems entail major investments and involve extensive efforts and organisational 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 production and distribution activities and they are designed to integrate and partially automate financial, resource management, commercial, after-sale, manufacturing, and other business functions into one system around a database [107].

A trend, especially in the mid-market, is to provide specific ERP modules as services. Such need generates the challenge for ERP system providers to offer mobile-capable ERP solutions. Another issue is the reporting and data analysis, which grows with the information needs of users. Research in big data analytics and business intelligence (BI) should become more tightly integrated with research and applications of ERP.

3.10 Customer relationship management

In Internet-based retailing, which is the preferred business model followed in MC, customer information management is a necessity. In particular, exploiting consumer data, such as purchase history, purchasing habits, and regional purchasing patterns, are the cornerstone of success for any company active in MC. In business-to-business and business-to-customer, CRM suites are thus indispensable. According to Strauss and Frost [108], CRM involves, as a first step, research to gain insight so as to identify potential and current customers. In a second step, customer information is used to differentiate the customer base according to specific criteria. Finally, the third step involves customised offerings for those customers that are identified as "superior" from the previous phase, enabling thus, the targeted offering of customised products. During the first step of identification of customers, market research and consumer behaviour models are used. In a second phase, for establishing differentiation techniques, data mining and KPIs assessment are used. Finally, for fine-tuning customisation options, information such as price, variants, promotions, and regions are examined [109].

As Internet becomes ubiquitous in business, CRM has been acknowledged as an enabler for better customisation since it offers management of the new market model less disruptively. Internet-enabled CRM tools also bring the customer closer to the enterprise and allow highly responsive customer-centred systems without significant increase in costs [110]. e-CRM implementations have been assessed in the study [111]. Noticeably, most major CRM suite vendors have started providing cloud-based services, a business model that suits SMEs that cannot afford huge ICT investments. Based on the balanced scorecard method, the study in [112] assessed e-CRM performance using 42 criteria in a number of companies. The results show that a successful CRM implementation is associated with tangible outcomes, such as improvements in financial indicators, customer value, brand image, and innovation. Finally, the latest generation of CRM tools, referred to as social CRM, exploit social networking technology to harness information about customer insights and engagement.

3.11 Cloud computing and manufacturing

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" [113]. 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 [114], collaborative and adaptive process planning [115], online tool-path programming based on real-time machine monitoring [116], manufacturing collaboration and data integration based on the STEP standard [117], and collaborative design [118].

The benefits of cloud for improving manufacturing network performance are numerous (Table 1). Cloud can offer increased mobility and ubiquitous information to an enterprise since the solutions it offers are independent of device and location. Moreover, computational resources are virtualised, 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 [119]. However, there are some considerations also (Table 1). A main challenge for the adoption of cloud in manufacturing is the lack of awareness on security issues. This major issue can be addressed using security concepts and inherently safe architectures, such as privately deployed clouds. The security concept must include availability of ICT systems, network security, software application security, data security, and finally operational security. Considerable funding is spent by the global security software market, in order to alleviate security issues. Recent reports show that the expenditure on cloud security is expected to rise 13-fold by 2018 [120, 121]. Moreover, there is the possibility of backlash from

Table 1 Benefits and drawbacks of cloud technology for manufacturing

Benefits	Drawbacks
Increased mobility that allows decentralised and distributed SCM	Lack of standardisation and protocols create hesitation in adoption of Cloud solutions
Ubiquitous access to information context empowering decision-making	Security and lack of awareness on security issues, especially in SMEs, that are part of supply chains/clusters
Device and location independent offering context-sensitive visualisation of crucial data relevant to the mfg. network	Privacy issues generate legal concerns, identity management, access control, and regulatory compliance
Hidden complexity permits the diffusion of ICT solutions even to traditional, averted by disruptive solutions, sectors	Dependence on the cloud provider (provider stops providing services, absence of contracts/regulation)
Virtualised and scalable on-demand computational resources (problems of varied computational complexity)	Loss of control over data (assuring smaller companies that their data are not visible by anyone in the supply chain, but the owner is challenging)
Low cost for SMEs that cannot afford huge ICT investments and lack the know-how to maintain them	

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 [122].

4 Challenges for future manufacturing

MC provides a set of enabling concepts and methods for providing the customer with products they desire and for organising production resources and networks to realise these products. However, on a practical strategic, tactical, and operational level, the tools for the realisation of MC are under development and refinement and a number of issues related to the design of manufacturing networks and their management are still not tackled in a holistic integrated manner. Several particular challenges need to be addressed as described below. Possible solutions are also proposed in the context of supporting a more efficient implementation of MC and personalisation.

4.1 Challenges for the manufacturing network life cycle

Regarding supplier selection, existing frameworks that handle both selection of suppliers, order allocation, and capacity planning are rare in the literature. Therefore, inconsistencies between the design phase and the actual implementation of the supply chain are a common issue. The problem most commonly treated jointly with supplier selection is the order allocation problem, as reported in the works of [123–125] among other. Moreover, several studies point out the difficulties of coordination between large networks of stakeholders. Potential solutions in novel approaches to tackling the issues generated in supply chain coordination for the procurement of customised products are proposed, such as in [126], where organisation flatness is proposed as a mediator for enhancing MC capability. Flatness in cross-plant and cross-functional organisation alleviate the need to decisions to pass through multiple layers of executives, simplifying coordination and information sharing [127]. Among the several challenges for configuring robust manufacturing networks to satisfy MC are the need for frameworks that handle the entire order fulfilment life cycle (from product design to delivery), methods to allow easy modelling and experimentation of what-if scenarios and deeper examination of the impact of product variety on the performance of manufacturing networks. On the field of SCM, 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 [128]. Available solutions for lot sizing are following traditional approaches and are not able to address the increasing complexity of problems arising in the modern manufacturing network landscape. The economic order quantity (EOQ), established for more than 100 years, still forms the basis of recent lot sizing practices. In setups of complex and changeable products, the problem of lot sizing becomes extremely complex. Nevertheless, the optimality of inventory and capacity planning is often neglected due to increased complexity of the supply chain problems which comes with higher priority. For instance, in multi-agent manufacturing systems, each agent resolves inventory issues in its domain partition level, without clear global optimisation overview [37]. Furthermore, the broader role of logistics capabilities in achieving supply chain agility has not been addressed from a holistic conceptual perspective [129]. Therefore, an open research question is the relationship between logistics capabilities and supply chain agility. Regarding ERP suites, apart from their apparent benefits, the reported successful implementations of ERP systems are limited when considering implementation costs and disruptions caused in production [130]. One reason for the low success rates in ERP implementations is attributed to the organisation changes needed for the industry that disrupt normal flow of business. Another reason is that production planning, a core function handled by currently deployed closed-loop MRPII (manufacturing resource planning) and ERP suites, is performed through the fundamental MRP (material requirements planning) logic [1, 131]. This leads to the generation of low-detail shop-floor schedules, assuming infinite production capacity and constant time components, thus leading to inflated lead times [132]. 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 [133, 134]. Challenges in the field of product data management (PDM) are related to the efficiency of these systems with regard to studying factors that affect the accessibility of product data, for instance, the nature of data in different timeframes of a development, the relationship between the maturity of the data, and the probability of them being modified [135]. The deployment and tight integration of product life cycle management (PLM) tools must also be considered since they bring an abundance of benefits against current manufacturing challenges. Yet these benefits are still not appreciated by many industrial sectors, mainly due to the following reasons: (1) they are complex as a concept and understanding their practical application is difficult, (2) they lack a holistic approach regarding the product life cycle and its underlying production life cycle and processes, and (3) the gap between research and industrial implementation is discouraging [136]. Concerning CRM, although data rich markets can exploit the feedback of consumers through social networks to identify user polarity towards a product–service, improve its design, and refine a product service system (PSS) offering, only few initiatives have tapped that potential.

Further challenges that are related indirectly to the previous aspects are discussed hereafter. Concerning individual disparate software modules, it is often observed that they contradict each other because they refer to not directly related manufacturing information and context. 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. 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) [137]. 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 computer-aided process planning (CAPP) systems are incapable of adjusting to dynamic operations, and a process plan, created in advance, is found improper or unusable to specific resources [138]. Highlighted challenges for life cycle 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 [139, 140]. Regarding knowledge management and modelling, reusable agent-oriented knowledge management frameworks, including the description of agent roles, interaction forms, and knowledge description, are missing [141]. 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 constrained [142]. Furthermore, 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 [143]. 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, it cannot fully solve the interoperability and extensibility issues since the interoperability depends on how the different software and users define contents of data models [144]. Concerning material flow simulation, it can be very time-consuming to build and verify large models with standard commercial-off-the-shelf software. Efficient simulation model generation will allow the user to simplify and accelerate the process of producing correct and credible simulation models [145]. Finally, 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.

4.2 Solutions for addressing the challenges in the future manufacturing landscape

A view of the manufacturing system of the near future that incorporates the latest trends in research and ICT developments and can better support MC is shown in Fig. 12. It is envisioned that, fuelled by disruptive technologies such as the IoT and cloud technology, entities within supply chains will exchange information seamlessly, collaborate more efficiently, and share crucial data in real time. Data acquisition, processing, and interpretation will be

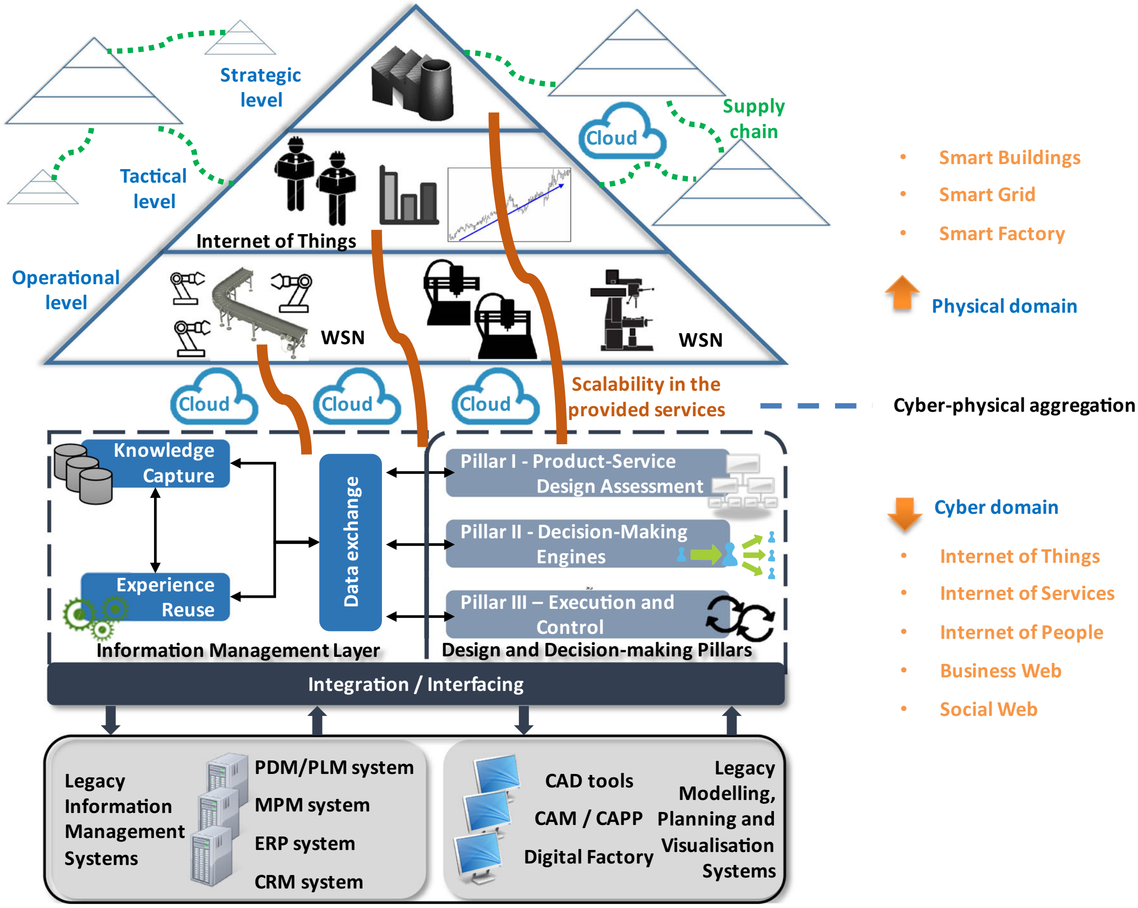


Fig. 12 View of manufacturing in the near future

supported by wireless sensor networks. The information will be available on demand and on different degrees of granularity empowered by big data analytics. Drilling down to specific machine performance and zooming out to supply chain overview will be practically feasible and meaningful. The distinction between the physical and the digital domains will become less clear. Besides, physical resources are already considered as services under the cloud manufacturing paradigm. A tighter coupling and synchronisation between the life cycles of product, production, resources, and supply chains will be necessary, while the distinction between cyber and physical domains will become hazier. A discussion on potential directions for adhering to this view of manufacturing is provided hereafter.

New technologies and emerging needs render traditional SCM and manufacturing network design models obsolete. To support manufacturing network design, planning, and control, a framework that integrates, harmonises, processes, and synchronises the different steps and product-related information is needed. The framework will be capable of supporting the decision-making procedure on all organisation levels in an integrated way, ranging from the overall management of the manufacturing network, down to the shop-floor scheduling fuelled by big data analytics, intuitive visualisation means, smart user interfaces, and IoT. An alignment and coordination between supply chain logistics and master production schedules with low-level shop-floor schedules is necessary for short-term horizons. The framework needs not be restricted on a particular manufacturing domain; since it is conceived by addressing universal industrial needs, its applicability to contemporary systems is domain-independent. The constituents of the framework are described hereafter.

The system will be supported by automated model-based decision-making methods that will identify optimum (or near-optimum) solutions to the sub-problems identified above, such as for the problem of the configuration of manufacturing networks capable of serving personalised 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.

The joint handling of order allocation, supplier selection, and capacity planning is necessary to alleviate inconsistencies between the supply chain design and implementation phases under a flatness concept. The incorporation of the entire order fulfilment life cycle is additionally envisioned, enhanced with methods that allow easy modelling and experimentation on what-if scenarios. The relationship between logistics capabilities and supply chain agility can also be revealed through this holistic view of the constituents of the supply chain.

Regarding SCM, collaboration concepts based on cloud computing and cloud manufacturing are a game changer. Through the sharing of both ICT as well as manufacturing resources, SMEs can unleash their innovation potential and thus compete more easily in the global market.

Further to that, the measurement and management of the manufacturing network complexity should be considered as a core strategic decision together with classical objectives of cost, time, and quality. Handling a variety of market excitations and demand fluctuations is the standard practice even today in many sectors, while this trend is only bound to intensify. In parallel, a risk assessment engine should correlate complexity results and leverage them into tangible risk indicators. Complexity can then be efficiently channelled through the designed network in the less risky and unpredictable manner.

To address the increasing complexity of problems arising in the modern manufacturing network landscape, the lot sizing and material planning need to be tightly incorporated to the production planning system. The consideration of capacitated production constraints is needed in order to reflect realistic system attributes. A shared and distributed cloud-based 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). This record should be pervasive and contain dataset groups relevant to intra-departmental variables, as well as datasets visible only to suppliers and relevant stakeholders, in order to increase the transparency of operations.

The mistreated issues of deployment and tight integration of PLM, ERP, and CRM tools must also be tackled through interfacing of legacy software systems and databases for seamless data exchange and collaboration. Software as a service PLM, ERP, and CRM solutions available to be purchased per module will be the ideal ownership model since it allows greater degree of customisation of solutions, more focused ICT deployment efforts, and reduced acquisition costs. CAD/CAM, PDM, and MPM (manufacturing process management) systems and databases will be interfaced and interact with digital mock-ups of the factory and product–services solutions as well for synchronising the physical with the digital worlds. In addition, 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 formalised in order to be exploited by a knowledge reuse mechanism that utilises semantic reasoning. This mechanism is comprised of an ontological model that is queried by the knowledge inference engine and allows the retrieval of knowledge and its utilisation in design and planning phases. The developments should also mediate the deeper examination of the impact of product variety on the performance of manufacturing networks.

In parallel, there is an urgent need of standardisation and harmonisation of data representation for manufacturing information, for example: the product information (BoM, engineering-BoM and manufacturing-BoM [146]), 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, for instance, design structure matrices (DSM) [147], 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 and cost, and effect on the overall reliability) will be quantified and will be incorporated in the decision-making process.

Last but not least, it should be noted that the components of the proposed framework must be offered following a software as a service delivery method and not as a rigid all-around platform. The framework should act as a cloud-based hub of different solutions, offering web-based accessibility through a central “cockpit” and visualisation of results through common browser technology and handheld devices (tablets, smartphones, etc.).

5 Conclusions

The ability to customise a product/service is offered to consumers for many years now, while truly unique products will be requested in the near future by users around the globe [148] using the Internet as a means of integration in the design process. In addition, the shortening of life cycles and time to market, increased outsourcing, manufacturing at dispersed sites, and the diverse cooperation in networks increase the complexity of production [149]. Agility, reconfigurability, and synchronisation from process up to supply chain levels are necessary in order for companies to respond effectively to the ever-changing market needs [150]. Driven by the ever-increasing need to reduce cost and delivery times, OEMs are called to efficiently overcome these issues by designing and operating sustainable and efficient manufacturing networks.

This work reviewed the existing literature related to the basic aspects of a manufacturing network life cycle within the MC landscape. The focus was to study existing practices and highlight the gaps in the current approaches related to these aspects of manufacturing network design, planning, and operation. Afterwards, the identification of future directions of academic and industrial research is proposed. Departing from that, major drivers and enabling technologies are identified and concepts that can lead to a more sustainable implementation of MC are proposed.

Summing up, the theoretical foundations of MC have been laid for many years now [150]. Still, there is an apparent gap between the theoretical and the actual application of MC, and bridging this gap is a challenging task that needs to be addressed. A safe conclusion reached is that the complexity generated in manufacturing activities due to the exploding product variety requires a systematic approach to be considered during the design, planning, and operating of the entire manufacturing system [5]. All in all, piecemeal digitalisation of manufacturing network is not a viable option; revisiting of the entire supply and manufacturing network life cycle is essential for sustainability. The pursuit for a smoother, more efficient, more rewarding, and eco-friendly manufacturing is ongoing.

References

1. Chryssolouris G (2006) Manufacturing systems: theory and practice, 2nd edn. Springer, New York
2. Chryssolouris G, Papakostas N, Mavrikios D (2008) A perspective on manufacturing strategy: produce more with less. CIRP J Manuf Sci Technol 1(1):45–52
3. Tolio T, Ceglarek D, ElMaraghy HA, Fischer A, Hu SJ, Laperrière L, Newman ST, Váncza J (2010) SPECIES—co-evolution of products, processes and production systems. CIRP Ann Manuf Tech 59(2):672–693
4. ElMaraghy H, Schuh G, ElMaraghy W, Piller F, Schönsleben P, Tseng M, Bernard A (2013) Product variety management. CIRP Ann Manuf Tech 62(2):629–652
5. Chryssolouris G, Papakostas N (2014) Dynamic Manufacturing Networks in a Globalised Economy. In: 8th International conference on digital enterprise technology—DET 2014. Keynote Presentation, 25–28 Mar 2014, Stuttgart, ISBN: 9783839606971
6. Doukas M, Psarommatis F, Mourtzis D (2014) Planning of manufacturing networks using an intelligent probabilistic approach for mass customised products. Int J Adv Manuf Tech 74(9):1747–1758
7. Mourtzis D, Doukas M, Psarommatis F (2015) A toolbox for the design, planning, and operation of manufacturing networks for mass customization. J Manuf Syst 36:274–286
8. Santoso T, Ahmed S, Goetschalckx Shapiro A (2005) A stochastic programming approach for supply chain network design under uncertainty. Eur J Oper Res 167(1):96–115
9. Da Silveira G, Borenstein D, Fogliatto FS (2001) Mass customisation: literature review and research directions. Int J Prod Econ 72(1):1–13
10. Gunasekaran A, Ngai EWT (2012) The future of operations management: an outlook and analysis. Int J of Prod Econ 135(2):687–701
11. Mourtzis D, Doukas M (2014) The evolution of manufacturing systems: From craftsmanship to the era of customisation. In Modrak V, Semanco P, (eds) Design and management of lean production systems. IGI Global, ISBN13: 9781466650398, http://www.igi-global.com/book/handbook-research-design-management-lean/84172/
12. Chandler AD (1990) Scale and scope. Harvard University Press, Cambridge
13. Hounshell A (1984) From the American system to mass production, 1800–1932: the development of manufacturing technology in the United States. Johns Hopkins University Press, Baltimore
14. Piller FT, Möslein KM (2002) From economies of scale towards economies of customer interaction: value creation in mass customisation based electronic commerce. In: 15th Bled electronic commerce conference, TU München, pp 214–228
15. Thirumalai S, Sinha K (2011) Customisation of the online purchase process in electronic retailing and customer satisfaction: an online field study. J Oper Manag 29:477–487
16. Ueda K, Takenaka T, Váncza J, Monostori L (2009) Value creation and decision-making in sustainable society. CIRP Ann Manuf Tech 58(2):681–700
17. Koren Y (2009) The global manufacturing revolution, 2nd edn. Wiley, Hoboken
18. Fogliatto FS, da Silveira GJC (2008) Mass Customisation: a method for market segmentation and choice menu design. Int J Prod Econ 111(2):606–622
19. Fogliatto FS, Da Silveira G, Borenstein D (2012) The mass customisation decade: an updated review of the literature. Int J Prod Econ 138(1):14–25
20. Hu SJ, Ko J, Weyand L, ElMaraghy HA, Kien TK, Koren Y, Bley H, Chryssolouris G, Nasr N, Shpitalni M (2011) Assembly system design and operations for product variety. CIRP Ann Manuf Tech 60(2):715–733
21. Holweg M, Disney SM, Hines P, Naim MM (2005) Towards responsive vehicle supply: a simulation-based investigation into automotive scheduling systems. J Oper Manag 23(5):507–530
22. Elias S (2002) New car buyer behaviour. 3DayCar Research Report. Cardiff Business School
23. Knight K (2007) Survey: 89 % of consumers prefer online shopping. Bizreport. http://www.bizreport.com/2007/12/survey_89_of_consumers_prefer_online_shopping.html
24. Helms M, Ahmadi M, Jih W, Ettkin L (2008) Technologies in support of mass customisation strategy: exploring the linkages between e-commerce and knowledge management. Comput Ind 59(4):351–363

25. Franke N, Keinz P, Schreier M (2008) Complementing mass customisation toolkits with user communities: how peer input improves customer self-design. J Prod Innov Manag 25(6):546–559
26. Chen L, Song Z, Feng L (2004) Internet-enabled real-time collaborative assembly modelling via an E-assembly system: status and promise. Comput Aided Des 36(9):835–847
27. Feldmann K, Rottbauer H, Roth N (1996) Relevance of assembly in global manufacturing. CIRP Ann Manuf Tech 45(2):545–552
28. Janardanan VK, Adithan M, Radhakrishnan P (2008) Collaborative product structure management for assembly modelling. Comput Ind 59(8):820–832
29. Warren NA (2005) Internet and globalisation. In: Gangopadhyay P, Chatterji M (eds) Economics of globalisation. Ashgate, USA
30. Oliver J, Houlihan JB (1986) Logistics management—the present and the future. In: Proceedings of 1986 BPICS conference, p 91–99
31. Wilding R (1998) The supply chain complexity triangle: uncertainty generation in the supply chain. Int J Phys Distrib Logist Manag 28(8):599–616
32. Gereffi G (1999) International trade and industrial upgrading in the apparel commodity chain. J Int Econ 48(1):37–70
33. Váncza J, Monostori L, Lutters D, Kumara SR, Tseng M, Valckenaers P, Van Brussel H (2011) Cooperative and responsive manufacturing enterprises. CIRP Ann Manuf Tech 60(2):797–820
34. Wiendahl HP, ElMaraghy HA, Nyhuis P, Zäh MF, Wiendahl HH, Duffie N, Brieke M (2007) Changeable manufacturing—classification, design and operation. CIRP Ann Manuf Tech 56(2):783–809
35. Tolio T, Urgo M (2007) A rolling horizon approach to plan outsourcing in manufacturing-to-order environments affected by uncertainty. CIRP Ann Manuf Tech 56(1):487–490
36. Chui M, Loffler M, Roberts R (2010) The internet of things. McKinsey Quarterly, New York
37. Monostori L, Váncza J, Kumara SRT (2006) Agent-based systems for manufacturing. CIRP Ann Manuf Tech 55(2):697–720
38. Mourtzis D, Doukas M, Psarommatis F (2013) Design and operation of manufacturing networks for mass customisation. CIRP Ann Manuf Tech 63(1):467–470
39. Cunha PF, Ferreira PS, Macedo P (2008) Performance evaluation within cooperate networked production enterprises. Int J Comput Int Manuf 21(2):174–179
40. Weber CA, Current JR, Benton WC (1991) Vendor selection criteria and methods. Eur J Oper Res 50(1):2–18
41. Wu C, Barnes D (2011) A literature review of decision-making models and approaches for partner selection in agile supply chains. J Purch Suppply Manag 17(4):256–274
42. Tracey M, Tan C (2001) Empirical analysis of supplier selection and involvement, customer satisfaction, and firm performance. Supply Chain Mana Int J 6(4):174–188
43. Ellram LM (1990) The supplier selection decision in strategic partnerships. J Purch Mater Manag 26(4):8–14
44. Lee AHI et al (2009) A green supplier selection model for high-tech industry. Expert Syst Appl 36(4):7917–7927
45. Ni M, Xu X, Deng S (2007) Extended QFD and data-mining-based methods for supplier selection in mass customisation. Int J Comput Integr Manuf 20(2-3):280–291
46. Hou J, Su D (2007) EJB-MVC oriented supplier selection system for mass customisation. J Manuf Tech Manag 18(1):54–71
47. Hou J, Su D (2006) Integration of web services technology with business models within the total product design process for supplier selection. Comput Ind 57(8–9):797–808
48. Deng X, Hu Y, Deng Y, Mahadevan S (2014) Supplier selection using AHP methodology extended by D numbers. Expert Syst Appl 41(1):156–167
49. Scott J, Ho W, Dey PK, Talluri S (2015) A decision support system for supplier selection and order allocation in stochastic, multi-stakeholder and multi-criteria environments. Int J Prod Econ 166:226–237
50. Tan PS, Lee S, Goh AES (2012) Multi-criteria decision techniques for context-aware B2B collaboration in supply chains. Dec Support Syst 52(4):779–789
51. Ho W, Xu X, Dey PK (2010) Multi-criteria decision making approaches for supplier evaluation and selection: a literature review. Eur J Oper Res 202(1):16–24
52. Nonaka I (1994) A dynamic theory of organizational knowledge creation. Organ Sci 5(1):14–37
53. Ahmad S, Schroeder RG, Mallick DN (2010) The relationship among modularity, functional coordination, and mass customization. Eur J Innov Manag 13(1):46–61
54. Kanda AA, Deshmukh SG (2008) Supply chain coordination: perspectives, empirical studies and research directions. Int J Prod Econ 15(2):316–335
55. Mourtzis D, Doukas M, Psarommatis F (2012) A multi-criteria evaluation of centralised and decentralised production networks in a highly customer-driven environment. CIRP Ann Manuf Tech 61(1):427–430
56. Chase RB (1998) Production and operations management: manufacturing and services. Irwin McGraw Hill, New York
57. Windt K, Böse F, Philipp T (2008) Autonomy in production logistics: identification, characterisation and application. Robot Comput Int Manuf 24(4):572–578
58. Mourtzis D (2011) Internet based collaboration in the manufacturing supply chain. CIRP J Manuf Sci Tech 4(3):296–304
59. Li X, Wang Q (2007) Coordination mechanisms of supply chain systems. Eur J Oper Res 179(1):1–16
60. Jain AS, Meeran S (1999) Deterministic job-shop scheduling: past, present and future. Eur J Oper Res 113(2):390–434
61. Mula J, Peidro D, Mandronero MD, Vicens E (2010) Mathematical programming models for supply chain production and transport planning. Eur J Oper Res 204:377–390
62. Wu C, Barnes D, Rosenberg D, Luo X (2009) An analytic network process-mixed integer multi-objective programming model for partner selection in agile supply chains. Prod Plan Control 20(3):254–275
63. Liang TF, Cheng HW (2009) Application of fuzzy sets to manufacturing/distribution planning decisions with multi-product and multi-time period in supply chains. Expert Syst Appl 36:3367–3377
64. Zhang L, You X, Jiao J, Helo P (2008) Supply chain configuration with co-ordinated product, process and logistics decisions: an approach based on Petri nets. Int J Prod Res 47(23):6681–6706
65. Yao J, Liu L (2009) Optimisation analysis of supply chain scheduling in mass customisation. Int J Prod Econ 117(1):197–211
66. Thomas GJ, Griffin PM (1996) Coordinated supply chain management. Eur J Oper Res 196(94):1–15
67. Akçalı E, Çetinkaya S (2011) Quantitative models for inventory and production planning in closed-loop supply chains. Int J Prod Res 49(8):2373–2407
68. Lanza G, Peters S (2012) Integrated capacity planning over highly volatile horizons. CIRP Ann Manuf Tech 61(1):395–398
69. Lödding H, Yu KW, Wiendahl HP (2003) Decentralised WIP-oriented manufacturing control (DEWIP). Prod Plan Control 14(1):42–54
70. Buschkühl L, Sahling F, Helber S, Tempelmeier H (2008) Dynamic capacitated lot-sizing problems: a classification and review of solution approaches. OR Spectr 32(2):231–261

71. Aigbedo H (2007) An assessment of the effect of mass customisation on suppliers' inventory levels in a JIT supply chain. Eur J Oper Res 181(2):704–715
72. Monden Y (1983) Toyota production system: a practical approach to production management. Industrial Engineering and Management Press, ISBN: 978-0898060348
73. Berman B (2002) Should your firm adopt a mass customisation strategy? Bus Horiz 45(4):51–60
74. Zinn W, Bowersox DJ (1988) Planning physical distribution with the principle of postponement. J Bus Logist 9(2):117–136
75. Su JCP, Chang YL, Ferguson M (2005) Evaluation of postponement structures to accommodate mass customisation. J Oper Manag 23(3–4):305–318
76. Lee HL, Billington C, Carter B (1993) Hewlett Packard gains control of inventory and service through design for localisation. Interfaces 23(4):1–11
77. Rudberg M, Wikner J (2004) Mass customisation in terms of the customer order decoupling point. Prod Plan Control 15(4):445–458
78. Pagh JD, Cooper MC (1998) Supply chain postponements and speculation strategies: how to choose the right strategy. J Bus Logist 19(2):13–33
79. Mikkola JH, Skjott-Larsen T (2004) Supply chain integration: implications for mass customisation, modularisation and postponement strategies. Prod Plan Control 15(4):352–361
80. van Hoek RI (2000) The role of third-party logistics providers in mass customisation. Int J Logist Manag 11(1):37–46
81. Biao Y, Burns ND, Backhouse CJ (2004) Postponement: a review and an integrated framework. Int J Oper Prod Manag 24(5):468–487
82. Helo P, Szekely B (2005) Logistics information systems. Ind Manag Data Syst 105(1):5–18
83. Clarke MP (1998) Virtual logistics: an introduction and overview of the concepts. Int J Phys Distr Logist Manag 28(7):486–507
84. Lee HL, Padmanabhan V, Whang S (1997) Information distortion in a supply chain: the bullwhip effect. Manag Sci 43(4):546–558
85. Perea E, Grossmann I, Ydstie E, Tahmassebi T (2000) Dynamic modeling and classical control theory for supply chain management. Comput Chem Eng 24:1143–1149
86. Swaminathan JM, Smith SF, Sadeh NM (1998) Modelling supply chain dynamics: a multiagent approach. Dec Sci 29(3):607–632
87. Alexopoulos K, Papakostas N, Mourtzis D, Gogos P, Chryssolouris G (2008) Oscillator analogy for modelling the manufacturing systems dynamics. Int J Prod Res 46(10):2547–2563
88. Kelepouris T, Pramatari K, Doukidis G (2007) RFID-enabled traceability in the food supply chain. Ind Manag Data Syst 107(2):183–200
89. Wang LC, Lin YC, Lin PH (2007) Dynamic mobile RFID-based supply chain control and management system in construction. Adv Eng Inf 21(4):377–390
90. Bechini A, Cimino M, Marcelloni F, Tomasi A (2008) Patterns and technologies for enabling supply chain traceability through collaborative e-business. Inf Softw Technol 50(4):342–359
91. Xu DL, He W, Li S (2014) Internet of things in industries: a survey. IEEE Ind Inf 10(4):2233–2243
92. Reaidy PJ, Gunasekaran A, Spalanzani A (2015) Bottom-up approach based on internet of things for order fulfilment in a collaborative warehousing environment. Int J Prod Econ 159:29–40
93. Duffie NA, Roy D, Shi L (2008) Dynamic modelling of production networks of autonomous work systems with local capacity control. CIRP Ann Manuf Tech 57(1):463–466
94. Perona M, Miragliotta G (2004) Complexity management and supply chain performance assessment. A field study and a conceptual framework. Int J Prod Econ 90(1):103–115
95. Efthymiou K, Pagoropoulos A, Papakostas N, Mourtzis D, Chryssolouris G (2012) Manufacturing systems complexity review: challenges and outlook. Proc CIRP 3:644–649
96. Chryssolouris G, Efthymiou K, Papakostas N, Mourtzis D, Pagoropoulos A (2013) Flexibility and complexity: Is it a trade-off? Int J Prod Res 51(23–24):6788–6802
97. ElMaraghy W, ElMaraghy H, Tomiyama T, Monostori L (2012) Complexity in engineering design and manufacturing. CIRP Ann Manuf Tech 61(2):793–814
98. Maropoulos P (1994) Digital enterprise technology–defining perspectives and research priorities. Int J Comput Int Manag 16(7–8):467–478
99. Manufuture (2004) A vision for 2020, report of the high-level group, Nov 2004. http://www.manufuture.org/documents/manufuture_vision_en%5B1%5D.pdf
100. Bughin J, Chui M, Manyika CJ (2010) Big data, and smart assets: ten tech-enabled business trends to watch. McKinsey Quarterly, McKinsey Global Institute, New York
101. Xu X (2012) From cloud computing to cloud manufacturing. Robot Comput Int Manuf 28(1):75–86
102. Komoto H, Tomiyama T, Silvester S, Brezet H (2011) Analyzing supply chain robustness for OEMs from a life cycle perspective using life cycle simulation. Int J Prod Econ 134:447–457
103. Grewal CS, Enns ST, Rogers P (2010) Dynamic adjustment of replenishment parameters using optimum-seeking simulation. In: Simulation conference (WSC), proceedings of the 2010 winter conference, pp 1797–1808
104. Umeda S, Zhang F (2010) A simulation modelling framework for supply chain system analysis. In: Simulation conference (WSC), proceedings of the 2010 winter conference, pp 2011–2022
105. Hennies T, Reggelin T, Tolujew J, Piccut PA (2014) Mesoscopic supply chain simulation. J Comput Sci 5(3):463–470
106. Aloini D, Dulmin R, Mininno V (2012) Modelling and assessing ERP project risks: a petri net approach. Eur J Oper Res 220(2):484–495
107. Mourtzis D, Papakostas N, Mavrikios D, Makris S, Alexopoulos K (2012) The role of simulation in digital manufacturing-applications and outlook. Int J Comput Int Manuf 28(1):3–24
108. Strauss J, Frost R (2001) E-marketing, 2nd edn. Prentice-Hall, Englewood Cliffs
109. Vrechopoulos AP (2004) Mass customisation challenges in Internet retailing through information management. Int J Inf Manag 24(1):59–71
110. McIntosh RI, Matthews J, Mullineux G, Medland AJ (2010) Late customisation: issues of mass customisation in the food industry. Int J Prod 48(6):1557–1574
111. Kimiloglu H, Zarah H (2009) What signifies success in e-CRM? Mark Intell Plan 27(2):246–267
112. Woodcock N, Green A, Starkey M (2011) The customer framework, social CRM as a business strategy. J Database Mark Cust Strategy Manag 18:50–64
113. Mell P, Grance T (2009) Perspectives on cloud computing and standards. Information Technology Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg
114. Mourtzis D, Doukas M, Vlachou K, Xanthopoulos N (2014) Machine availability monitoring for adaptive holistic scheduling: A conceptual framework for mass customisation. In: 8th International conference on digital enterprise technology—DET 2014. 25–28 Mar, Stuttgart, ISBN: 9783839606971
115. CAPP-4-SMEs. Collaborative and adaptive process planning for sustainable manufacturing environments—CAPP4SMEs. EC

Funded Project, 7th Frammework Programme. Grant Agreement No.: 314024
116. Tapoglou N, Mehnen J, Doukas M, Mourtzis D (2014) Optimal tool-path programming based on real-time machine monitoring using IEC 61499 function blocks: a case study for face milling. In: 8th ASME 2014 international manufacturing science and engineering conference, 9–13 June 2014, Detroit, Michigan
117. Valilai OF, Houshmand M (2013) A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm. Robot Comput Int Manuf 29(1):110–127
118. Wu D, Thames JL, Rosen DW, Schaefer D (2012) Towards a cloud-based design and manufacturing paradigm: looking backward, looking forward. In: 32nd Computers and information in engineering conference ASME proceedings, Chicago, Illinois, 12–15, Aug, pp 315–328
119. Lewis G (2010) Basics about cloud computing. Software Engineering Institute, Carnegie Mellon University, Pittsburgh
120. Technavio Insights (2014) Global cloud security software market. http://www.trendmicro.com/cloud-content/us/pdfs/business/reports/rpt_technavio-global-security-software-market.pdf
121. MindCommerce (2014) Cloud security 2014: companies and solutions, July 2014. http://www.mindcommerce.com/cloud_security_2014_companies_and_solutions.php
122. Tao F, Zhang L, Venkatesh VC, Luo Y, Cheng Y (2011) Cloud manufacturing: a computing and service-oriented manufacturing model. Proc Inst Mech Eng Part B J Eng Manuf 225(10):1969–1976
123. Kannan D, Khodaverdi R, Olfat L, Jafarian A, Diabat A (2013) Integrated fuzzy multi criteria decision making method and multi-objective programming approach for supplier selection and order allocation in a green supply chain. J Clean Prod 47:355–367
124. Mafakheri F, Breton M, Ghoniem A (2011) Supplier selection-order allocation: a two-stage multiple criteria dynamic programming approach. Int J Prod Econ 132(1):52–57
125. Amin SH, Razmi J, Zhang G (2011) Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming. Expert Syst Appl 38(1):334–342
126. Yinan Q, Tang M, Zhang M (2014) Mass customization in flat organization: the mediating role of supply chain planning and corporation coordination. J Appl Res Tech 12(2):171–181
127. Zhang M, Zhao X, Qi Y (2014) The effects of organizational flatness, coordination, and product modularity on mass customization capability. Int J Prod Econ 158:145–155
128. Ramanathan U (2014) Performance of supply chain collaboration—a simulation study. Expert Syst Appl 41(1):210–220
129. Gligor DM, Holcomb MC (2012) Understanding the role of logistics capabilities in achieving supply chain agility: a systematic literature review". Supply Chain Manag Int J 17(4):438–453
130. Panorama Consulting (2014) ERP Report. Denver, Colorado: A Panorama Consulting Solutions Research Report
131. Olhager J (2013) Evolution of operations planning and control: from production to supply chains. Int J Prod Res 51(23–24):6836–6843
132. Plossl GW (2011) Orlicky's material requirements planning, 3rd edn. McGraw-Hill, New York
133. Su CJ (2009) Effective mobile assets management system using RFID and ERP technology. In: WRI international conference on communications and mobile computing, pp 147–151
134. Schabel S (2009) ERP—mobile computing. Thesis, Wien: Universität, Wien
135. Chan E, Yu KM (2007) A concurrency control model for PDM systems. Comput Ind 58(8–9):823–831
136. Schuh G, Rozenfeld H, Assmus D, Zancul E (2008) Process oriented framework to support PLM implementation. Comput Ind 59(2–3):210–218
137. Nee AYC, Ong SK, Chryssolouris G, Mourtzis D (2012) Augmented reality applications in design and manufacturing. CIRP Ann Manuf Tech 61:657–679
138. Wang L (2013) Machine availability monitoring and machining process planning towards cloud manufacturing. CIRP J Manuf Sci Tech 6(4):263–273
139. Brondi C, Carpanzano E (2011) A modular framework for the LCA-based simulation of production systems. CIRP J Manuf Sci Tech 4(3):305–312
140. Sihn W, Pfeffer M (2013) A method for a comprehensive value stream evaluation. CIRP Ann Manuf Tech 62(1):427–430
141. Dignum V (2006) An Overview of Agents in Knowledge Management. In: Umeda M (ed) Proceedings of INAP-05. Springer, pp 175–189
142. Mourtzis D, Doukas M (2014) Knowledge capturing and reuse to support mass customisation: a case study from the mould making industry. Proc CIRP 2:123–128
143. Valckenaers P, Brussel H, Verstraete P, Hadeli GB (2007) Schedule execution in autonomic manufacturing execution systems. J Manuf Syst 26(2):75–84
144. Shariatzadeh N, Sivard G, Chen D (2012) Software evaluation criteria for rapid factory layout planning, design and simulation. Proc CIRP 3:299–304
145. Lee JY, Kang HS, Kim GY, Noh SD (2012) Concurrent material flow analysis by P3R-driven modelling and simulation in PLM. Comput Ind 63(5):513–527
146. Xu HC, Xu XF, HE T (2007) Research on transformation engineering BOM into manufacturing BOM based on BOP. Appl Mech Mater 10–12:99–103
147. Eppinger SD, Browning TR (2012) Design structure matrix methods and applications. ISBN: 9780262017527
148. Zhang LL, Lee CKM, Xu Q (2010) article is part of a focus collection. Comput Ind 61(3):213–222
149. Simchi-Levi D (2010) Operation rules. MIT Press Ltd, Cambridge
150. Pine BJ (1992) Mass customisation: the new frontier in business competition. Harvard Business School Press, Boston