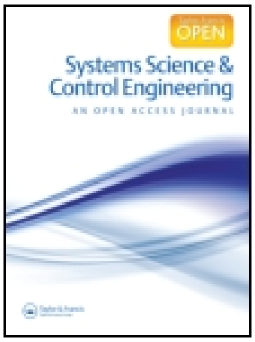

Taylor & Francis
Taylor & Francis Group

Systems Science & Control Engineering: An Open Access Journal

ISSN: (Print) 2164-2583 (Online) Journal homepage: https://www.tandfonline.com/loi/tssc20

Integration of supply networks for customization with modularity in cloud and make-to-upgrade strategy

Afshin Mehrsai, Hamid Reza Karimi & Klaus-Dieter Thoben

To cite this article: Afshin Mehrsai, Hamid Reza Karimi & Klaus-Dieter Thoben (2013) Integration of supply networks for customization with modularity in cloud and make-to-upgrade strategy, Systems Science & Control Engineering: An Open Access Journal, 1:1, 28-42, DOI: 10.1080/21642583.2013.817959

To link to this article: https://doi.org/10.1080/21642583.2013.817959

Systems Science & Control Engineering: An Open Access Journal, 2013
Vol. 1, No. 1, 28–42, http://dx.doi.org/10.1080/21642583.2013.817959

Integration of supply networks for customization with modularity in cloud and make-to-upgrade strategy

Afshin Mehrsai[a]*, Hamid Reza Karimi[b] and Klaus-Dieter Thoben[a]

[a]*Department of Production Engineering, Bremen University, BIBA GmbH, BIBA, Hochschulring 20, 28359 Bremen, Germany;*
[b]*Department of Engineering, Faculty of Engineering and Science, University of Agder, Grimstad, Norway*

(*Received 22 April 2013; final version received 18 June 2013*)

Today, integration of supply networks (SNs) out of heterogeneous entities is quite challenging for industries. Individualized demands are getting continuously higher values in the global business and this fact forces traditional businesses for restructuring their organizations. In order to contribute to new performances in manufacturing networks, in this paper a collaborative approach is recommended out of modularity structure, cloud computing, and make-to-upgrade concept for improving flexibility as well as coordination of entities in networks. A cloud-based framework for inbound and outbound manufacturing is introduced for complying with the production of individualized products in the turbulent global market, with local decision-makings and integrated performances. Additionally, the complementary aspects of these techniques with new features of products are conceptually highlighted. The compatibility of this wide range of theoretical concepts and practical techniques is explained here. A discrete-event simulation out of an exemplary cloud-based SN is set up to define the applicability of the cloud and the recommended strategy.

Keywords: supply network integration; cloud; modularity; customization; make-to-upgrade production strategy

1. Introduction

The phenomenon of globalization has been influencing all kind of industries, in particular, manufacturing branches. Thereby, a wide range of opportunities as well as threats are introduced to enterprises, which cause their businesses to survive or to collapse. In such an environment, customized orders by individual customers are no more dispensable but advantageous to pioneer enterprises. However, employment of new business strategies, models, technologies, and methodologies can assist enterprises and their supply networks (SNs) to be successful in the dynamic environment, i.e. volatile market, expansion of scale and scope, mass-customized demands, scarce resources, growing complexity in processes, cost competition, shifting authority from final producers to their suppliers and customers, etc. (Abdelkafi, 2008; Schön, 2012). On top of these challenges, paying attention to alternative customer demands with individual requirements – mentioned or not – while being integrated with other production and product stakeholders have got a high priority from enterprises. This concern has been interpreted by industries as a mass-customization (MC) strategy and individualization of products and operations. In order to deliver the right product to the right customer, enterprises have been trying to implement the strategic production approach of MC into their business models. Initially, Davis (1989) in 1987 coined the term of MC to reflect the large scope of providing personalized products and services (Fogliatto, da Silveira, & Borenstein, 2012).

Nevertheless, dealing with the challenge of customization, isolated enterprises was no longer functioning successfully in the market; they rather needed to collaboratively perform in harmony with the other players in the context of SNs (Pereira, 2009). Therefore, coordinating, administrating, and orchestrating the operations of such enterprises have become the biggest organizational challenges, to be dealt with by respective SNs. On the contrary, while cooperating with other supply members, individual enterprises, as independent entities, like to keep their own interests and concerns. This fact causes several contradictions between the members who have to competently cooperate and collaborate with each other to achieve the overall goal of the network. In other words, heterogeneous performances of single entities in the form of a SN necessitate an appropriate harmonization between them, by means of a comprehensive integration. This mission besides the individualization of products and processes together make a very complex performance environment that requires the employment of new strategies, methodologies, and state-of-the-art technologies (e.g. production techniques, information and communication technology (ICT), cloud computing, etc.).

Accordingly, exploitation of modularity approach and cloud computing together applied with the development of

---

*Corresponding author. Email: meh@biba.uni-bremen.de a compatible production/delivery strategy is seen as a novel solution in this paper. Combination of these on-hand tools and techniques has to result in better performances of SNs. Indeed, fulfillment of individual demands is sought, while harmonizing operations of networks through a wide range of virtual integrations is expected as well. Contrary to conventional industries, prospective SNs based on the framework, introduced in this paper, get more flexible structure with agility and responsiveness; which motivates the elaboration of this framework. In the following, the application of several techniques and strategies combined together to build this framework is conceptually justified.

In exploring this claim, the rest of the paper is organized as follows: first a brief literature review on the issue of integration in SNs is conducted. Then modularity for MC and individualization in its different aspects are discussed. Meanwhile, following the modularity a recommended production/delivery strategy compatible with the drafted environment and state-of-the-art cloud computing is competently introduced. Cloud computing as a service-oriented and coordination mean for achieving integration is explored later on. In order to verify the recommended strategy by means of the on-hand tools a discrete-event simulation model is developed and experimented at the final section. The conclusion and prospective works are explained at the end of the paper.

2. Literature review on integration of SN

Generally, since the beginning of initial cores in supply chains (SCs), the issue of integration in SCs and networks has been sought by scholars and practitioners. It is noticeable that in this paper SCs and SNs are treated the same, yet differ from each other in some cases. As Pereira (2009) mentions, a managed integration of SCs is required to achieve competitiveness, revenue, innovation, value, and cost reduction. However, he believes it is necessary to re-evaluate the traditional and vertically integrated model of SCs, i.e. by means of increased information sharing and cooperation, in order to achieve a global reach and local responsiveness. Danese, Romano, and Formentini (2013) study the effects of internal as well as external integration of SNs on responsiveness quality. They reveal that the use of an international supplier network positively moderates the impact of external integration on responsiveness, whilst this factor causes no contingent influence of internal integration on responsiveness. Chen, Daugherty, and Landry (2011) discuss the relationship between SC management (SCM) and SC integration (SCI) and argue that SCI is a key factor of SCM. They admire the important role of SCI in unifying business models of members (a cohesive network). However, the mystery of implementing (internally and externally) a practical integration is highlighted by them. A conceptual framework as a foundation for SCI is suggested in this work that encompasses four majors to integrate SCs as strategic priorities, integration of SC processes, SC capabilities, and performance.

Bosona and Gebresenbet (2011) comply with integration of SNs in the food industry and claim that integration in such causes positive effects on potential markets, logistics efficiency, environmental issues, and traceability of food quality. Their approach to supply network integration (SNI) refers to collaboration between several clusters of a food network which leads to competitiveness at a national and international level. While highlighting the roles of economic motivations, power, trust, and information sharing in collaboration, they suggest close information sharing among clusters and emphasize its importance in facing complex SNs. According to Flynn, Huo, and Zhao (2010), SCI has to provide a maximum value to the customer along with effective and efficient flows of materials, services, information, money, and decision. This ambition can be achieved by collaboratively managing intra- and inter-organizational processes among SC partners. They explore the effect of SCI on the performance, from customer and supply integration, and from network internal integration points of view. Their study shows internal integration is a basis for the other integrations. Moreover, internal and customer integrations have a more positive influence on the performance of the network than supplier integration. To achieve these results, they employed hierarchical regression to analyze the individual and interactional effects of the three aspects of SCI.

As Winkler (2009) argues, today, an integrated view of the value chain throughout SNs is rather considered for competitive advantages, so single enterprises are no longer at the center of consideration. In this regard, the optimal of single enterprises against a total optimum in an SN has to be compromised to achieve a suitable equilibrium mechanism. To achieve SNI, he suggests the following factors: the design of inter-organizational planning and controlling systems, the product design process, the stock management, the cooperative design of packages, the integration of common logistics service providers, and the synchronization of transports. The aim of configuring a common body for an SN by means of a high level of communication and arrangement of common strategic and operative measurements for all members is generally sought in that work. The communication and information system throughout SNs is seen as an important prerequisite for realizing flexibility as well as integration in SNs. The ability to share information between the members in the value-added processes, the capability of transferring information across a network, and the ability of synchronizing distributed information systems among the members are mentioned as the privileges of having information systems for SNs. Besides, the importance of compatibility and flexibility of interfaces among the information systems of partners with different technologies is emphasized as well. In doing so, usage of the extensible markup language (XML) protocol for exchanging business data through the Internet (web-based information systems) is suggested. Nonetheless, in order to reduce the complexity of network integration, filtering the accessibility to the data repository and inexpedient information for alternative partners is underlined.

Ye, Yang, Jiang, and Tong (2008) interpret the integration of SN by means of SCM as integration of information. They define SCM as an important operational strategy and as an integrator of key business processes spanning from customer to first-tier suppliers among a group of distributed enterprises that brings about value-added products, services, and information for all stakeholders. Meanwhile, effective information sharing as well as interoperability of inter- and intra-partners is seen as success factors. In this work, some arguments about web-based information integrators are given that include the pros and cons of XML, extensible markup language (OWL), and extensible markup language (SWRL). According to them, although XML complies with syntactic of data exchange, thanks to standardization of information's syntax by defining markups and structures of documents using tags, but comprehending the semantic of the data is challenging by means of that. Therefore, in case of web-based integration, they suggest OWL and SWRL to support web-based SCI.

Cheung, Cheung, and Kwok (2012) look into the issue of integration in SCs from three core technologies points of view as: visualization of topologies, network analysis, and knowledge-based system. Here, the influence of the turbulent performing circumstance on SCs members is noticed and, in contrary, effective recognition and optimization of their SCs by means of a holistic view is envisioned. They underline the necessity of agility, visibility, and integration of SCs for being responsive, effective, and efficient to the market dynamics, in the prompt mode. In doing so, their approach to a knowledge-based customization system for SCI covers a module-based system composed of the three core technologies which operate in a fully integrated and complementary manner with each other, as expected from modules. The significance of correctly interpreting the real-time data exchange (vertically and horizontally) from lower levels in an integrated system, like radio frequency identification (RFID) in logistics, to upper ones, like knowledge-based customization modules, is seen in this study.

In general, the latter papers above highlight a vertical and horizontal integration of SCs by means of compatible information systems which bridges daily operations by means of RFID, PDA, etc., to long-term planning and controlling strategies. Moreover, despite a limited addressing of modules in the last study on configuring an integrated information system of SCs, the real contribution of modularity and in particular processes modularity is missing in this work. However, a common approach of the most studies on SNI refers to flexible, simple, and effective data integration which has been a long time concern of scholars and practitioners. Thanks to new achievements in state-of-the-art ICT and the proliferation of the cloud computing concept, these desires are getting closer to practice.

3. Review of modularity and customization

A literature review unfolds the key role of MC in enabling industries to be competitive on the current and prospective market. Generally, MC aims at satisfying customers by means of considering their personality and subjective needs. This objective has been interpreted by producers as shifting from traditional mass-production (MP) to individualized products, while keeping the cost, volume, and efficiency of MP. As Smith, Smith, Jiao, and Chu (2012) mention, companies employ alternative configurations to make customized, tailored, standardized, or point-of-sale products. Salvador, De Holan, and Piller (2009) say MC "is a mechanism that is applicable to most businesses, provided that it is appropriately understood and deployed". Thus, MC is about aligning an organization with its customers' needs including reasonable costs. To fulfill these requirements, several enablers of MC can be listed as methodologies and techniques that make industries capable in producing customized products (Fogliatto et al., 2012), e.g. lean and agility, order elicitation, design postponement, design product platforms, SC coordination, decoupling point (DP), manufacturing technologies like flexible manufacturing systems, and information technologies like cloud computing.

On this basis, among several enablers of MC modularity and postponement strategy are seen as two main approaches of companies to producing large product diversity (Da Cunha, Agard, & Kusiak, 2007). As Mikkola (2007) explains MC "is enabled through modular product architectures, from which a wide variety of products can be configured and assembled". Kumar (2004) says "…?given that product modularity is a key element of a mass customization strategy". Indeed, modularity proceeds with the competitive factors of today's companies as sustainability, price, quality, flexibility, delivery, and service; which all can be fulfilled through a competent MC strategy. Additionally, some academic works consider modularity as an enabler for flexibility, agility, and performance growth of enterprises (Jacobs, Droge, Vickery, & Calantone, 2011; Schön, 2012). Modularity in design of products enables companies to employ assemble-to-order (ATO) production strategy throughout their SCs. However, other strategies like deliver-on-demand (DOD), make-to-order (MTO), or design-to-order (DTO) can also be adopted by customized-oriented companies. The purpose of these strategies is to integrate customers with various configurations into the several phases of product development and into production stakeholders by means of devising a DP.

Basically, modularity can be introduced by defining an integrated (and/or complex) body composed of several building-blocks independent in their identities and with

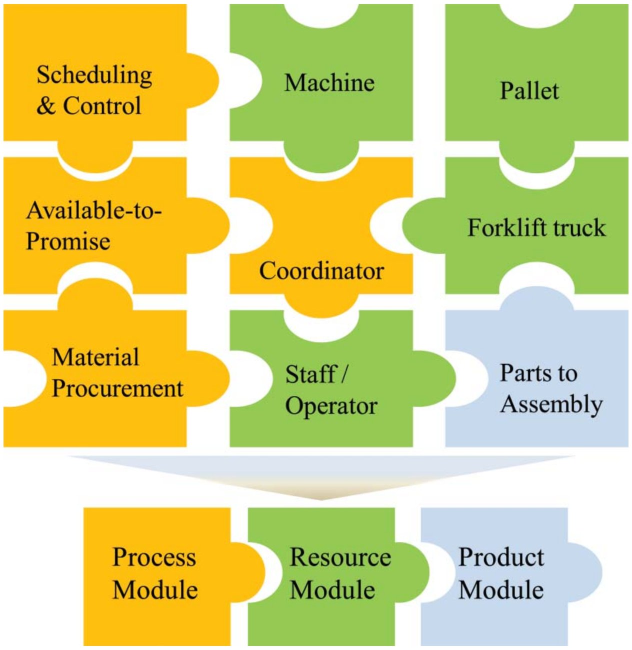

Figure 1. Combination of modules to response to a specific order.

interfaces to be purposefully combined as a whole. Reijers and Mendling (2008) explain the modularity as "the design principle of having a complex system composed from smaller subsystems that can be managed independently yet function together as a whole". Initially, modularity looks for the favorable goal of plug and play. In this regard, Schön (2012) defines a module as "a unit with strong connections between its components which can be removed non-destructively from a system as a whole". Generally, modularity approach can be applied to different aspects of an industrial system, i.e. products, processes, and resources (Bask, Lipponen, Rajahonka, & Tinnilä, 2010), see Figure 1. Modularity in product design plays a crucial role in customizing final products (goods) and in easing production procedure, whereas modularity in processes (Reijers & Mendling, 2008) can assist companies to deliver sustainable, adaptable, flexible, and customizable services either as final products or manufacturing/logistics operations. Modularity in resources, like modular manufacturing systems (Tsukune et al., 1993), can also be considered as a complementary aspect of a fully modular system, sought by MC throughout SNs.

3.1. Product modularity and make-to-upgrade (MTU) strategy

The literature review shows that modularity in resources has got less popularity than in processes and products. Particularly, in developing a product with the focus on the product use, modularity in processes and resources reflects less priority. Nonetheless, this issue requires more elaborations in studies for developing specific products with modular design and upgradability. In the near future, thanks to modular body of products with upgradability and traceability merits (e.g. product Avatar, Hribernik, Rabe, Thoben, & Schumacher, 2006), product obsolescence, waste, and scrap will drastically drop as great contributions to sustainability issue.

By considering the specifications of such future products (called "meta-product" by FP7 EU-projects), some advantages of modular vs. integrated design can be significantly highlighted as follows: scalability vs. non-scalability, simplicity vs. complexity, flexibility vs. rigidity, re-configurability vs. strictness, exchangeability vs. irreplaceability, upgradability vs. constancy or even downgradability, and sustainability vs. non-sustainability (shorter lifecycle of modules by longer lifecycle of the entire product). These are some privileges of modular design, which directly contribute to the requirements of MC. A well-known example of such modular design is LEGO. Each of these accompanied characteristic with modular approach can be seen as a driver for developing a framework of future products in beyond the state of the art.

In general, modularity in design of products brings about a large scale of product variety, while applying similar modules for alternative products (family). For instance, Porsche at a time period used a door module for three different car models. Or Nike, Adidas, and Dell follow the same concept of modularity to customize their products, yet by means of customer integration (Wong & Lesmono, 2013). Employment of WebPages for directly integrating customers to design their products is an outstanding advantage, which reflects demand penetration and ATO production strategies. Indeed, the already existing standard modules (a variety of building-blocks) lead to a vast scope of final products. Incorporation of customers towards the ramp-up phase of developing meta-products can be an extra privilege of customized-oriented SNs for better embedding the real expectations. In doing so, some integration techniques are, for instance, experiential customer integration techniques, data mining techniques, interactive techniques, and collaborative techniques (Pereira, 2009). However, early integration of customers, regarding various (individual) demands and some internal preparations (Koufteros, Vonderembse, & Jayaram, 2005), has its own difficulties and it may not achieve MC with efficient volume and cost (Smith et al., 2012). Despite several research papers, these impediments have hindered the proliferation of customer integration in practice. Thus, a new approach can be experimented in parallel.

A comprehensive literature review (Brun & Zorzini, 2009; Fogliatto et al., 2012; Jose & Tollenaere, 2005) shows direct and indirect impact of modularity on MC. Additionally, it is emphasized that information flow and processing is a success factor of effectiveness. Information flow is relevant to the exact customer requirements and awareness about the design functionalities and modularity (Ahmad,

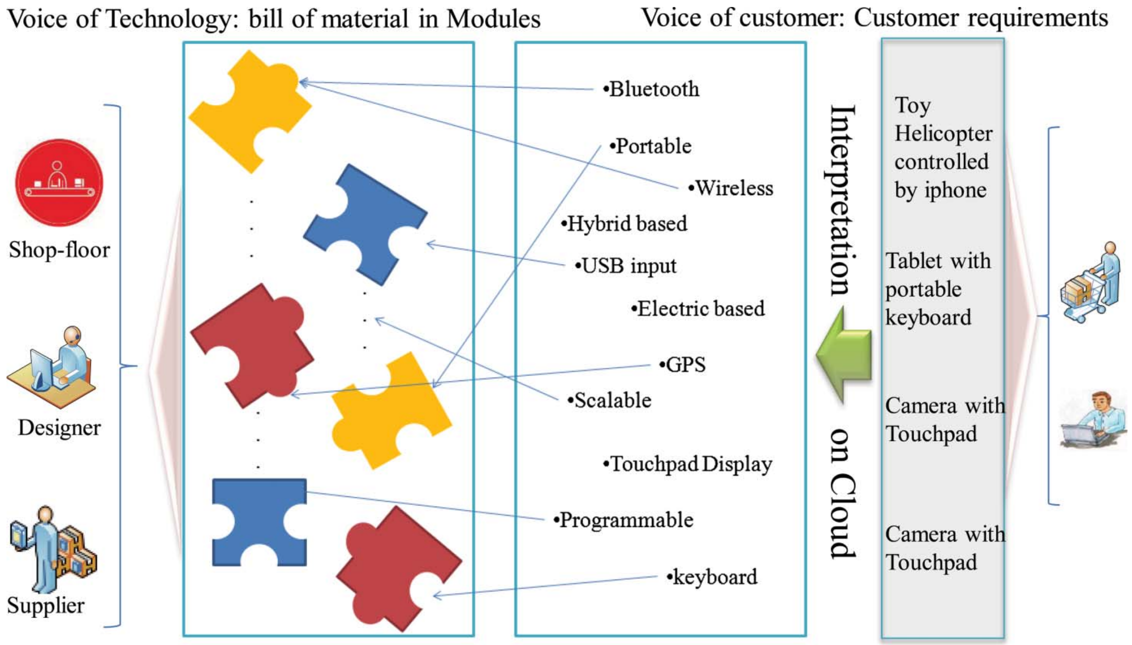

Figure 2. Integration of customer requirements to the respective modules.

Schroeder, & Mallick, 2010). Therefore, a competent survey is required to explore the suitability of alternative production strategies, e.g. ATO, MTO, DTO, for developing future customizable products. Moreover, it can be easily distinguished that products with customized features are more expensive and have longer lead times than the standard products (Xia & Rajagopalan, 2009). In general, in exploring the level of modularity and its influence on MC, several analytical factors for product characteristics are needed. In this regard, Brun and Zorzini (2009) recommend 13 variables to be monitored as follows: (1) product value, (2) product durability, 3. number of components of a product, (4) number of levels of bill of material (BOM), (5) type of BOM, (6) portion of service operations, (7) degree of customization of the product, (8) level of know-how to customize the product, (9) spend time for customizing the product, (10) cost of product customization, (11) number of variants of the product, (12) positioning of the order penetration point (OPP), and (13) the point of minimum configuration of BOM (the level of BOM characterized by the minimum number of items). Furthermore, modular design is a key factor in integrating customers into the process of developing their individual products (customer penetration) (Smith et al., 2012). Therefore, state-of-the-art customer integration methods have to be exploited to primarily couple the subjective requirements of customers to the respective modules, see Figure 2.

Indeed, integration of customers to SNs is not a new phenomenon. For instance, since early 1990s customers are able to directly buy their products (e.g. computers, apparel, etc.) from original equipment manufacturers (OEMs) over the Internet. Or in other words, customers try to find their best-fit products to their requirements and buy them, thanks to the provision of a wide range of manufacturers via the Internet (Tsao & Su, 2012). Nonetheless, this model is no more competent for the new world. In order to pursue the goal of "customizing with competent speed and cost", a new approach to production strategies seems necessary. In doing so, practitioners need to develop a special production strategy that support the postponement of customization at the latest point; to facilitate smoother production and customization, by avoiding the conventional barriers of early customer integration. In other words, a special form of postponement has to be realized that facilitate smoother production with lower cost. This strategy may dampen bullwhip effect in SNs, support easier demand forecasting with new and more accurate forecasting methods based on control theory for better determining dynamics of networks, see Che, Chiang, and Kuo, (2012) for more information.

Correspondingly, modular design brings the necessary characteristics to products and processes that ease the postponement strategy and facilitate a precise forecasting as well. Indeed, the characteristics of future products (e.g. upgradability) provide an opportunity to manufacturers to develop standard modules, which can be easily assembled by the end-user; to configure alternative final products without expensive modification in upstream echelons. This concept, to be sought by modular product developers, introduces a new production/delivery strategy, called by the authors "make-to-upgrade (MTU)", see Figure 3.

In fact, pursuing the MTU strategy urges SNs to integrate the real customer requirements into their modular development phase as early as possible, whilst

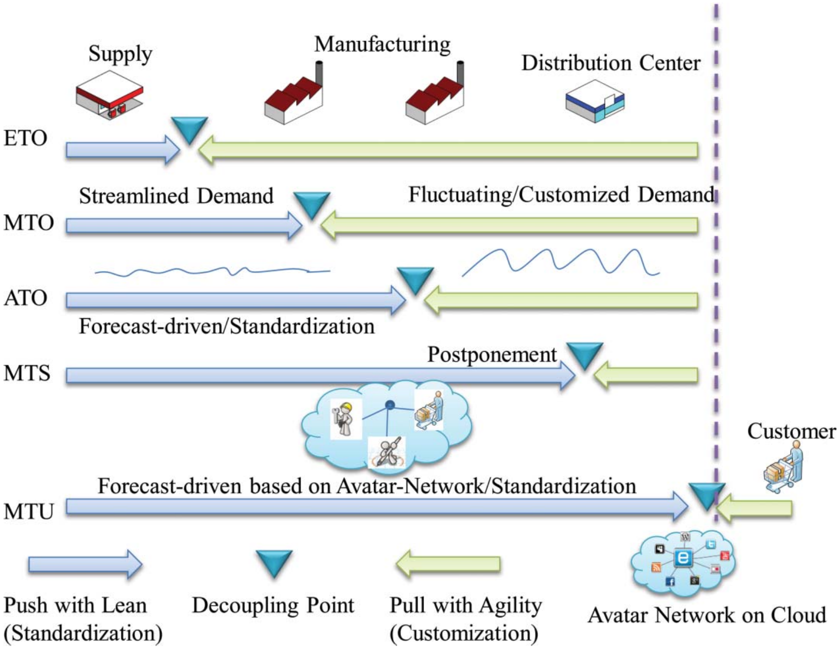

Figure 3. Production strategies for developing mass-customised product from state of the art to beyond.

postponing the assembly of the modules and configuration of final products to the customer side. This novelty assists enterprises in introducing a variety of customized products with fewer concerns about the loss of product obsolescence or idleness. Moreover, new studies about robustness of SCs in terms of inventory optimal approach regarding fluctuations in inputs and outputs, using control theory, contribute to design a robust MTU strategy for SNs. A good example for such networks that the customer lead time plays a crucial role and the entire supply process is sensitive to the customer safety and satisfaction is blood SC. This chain must react to customer needs as soon as possible, while following exact requirements. Control theory and artificial intelligence techniques can contribute to the design of robust and resilient SNs, see Li and Liao (2012) for more information.

However, member companies of a network with the approach of modularity, set standard operations for producing their products (split in modules), while deriving modular processes at the very downstream of their SCs. Whereas MTU smoothes the production operations with a very adequate speed, customization is realized at its most competent level too. The recommended MTU strategy may be more understandable once combining the performance of IKEA (Bocconcelli & Tunisini, 2009) and the concept of LEGO in postponement and modularity. However, the further step beyond the state of the art is to provide an environment to make possible the assembly phase of modules at the customer location. This draws a virtually integrated social network that all stakeholders of products are connected and engaged like the concept of product Avatar (Hribernik et al., 2006).

3.2. Process and resource modularity

As stated, thanks to new achievements in ICT, modularity concept is broadening its boarders over product design to processes and resources design (physical or nonphysical). Accordingly, the competitive advantages of prospective SNs are focused on higher agility and flexibility in performances and products, while being more coordinated with other partners. To achieve this target, enterprises of an SN need to comply with individualization of their products in a shorter time and with less cost, whilst adapting their performances to the other sites. The new approach towards this objective is to equip individual enterprises as well as SNs with flexible building-blocks, instead of their current concrete bodies. This contribution leads to an appropriate combination of the building-blocks (spanning from internal objects/processes of a single company to single partners of a network) to fulfill a specific goal/demand of the system. Such enterprises (and consequent networks) are able to purposefully manage their merits in each branch (products, processes, and resources) to meet market dynamics and customized orders, which is hardly or not achievable otherwise (Figure 1).

Extension of modularity into processes and resources results in an organization and/or in an SN with a flow body which can offer several alternative shapes regarding current requirements and constraints. In other words, such a network can split its performances into modules and adjust them as required. This notion is fully reflected into the collaborative networks concept with fully flexible bodies which configure temporal nets upon short-term projects (Thoben & Jagdev, 2001). However, despite lots of positive contributions, modularity by itself can be an intricacy-driver throughout SNs as well. The huge scale and scope of modules in each branch (i.e. product, process, and resource) cause higher complexity in performances, while adjustment of them for specific orders can be time consuming and costly. In particular, realization of modularity in processes and resources is quite an intricate task in terms of planning and control of them, since they are abundant and specialized. ICT has been supporting competent enterprises and networks to manage their processes, so that less complication as well as more flexibility can be experienced. The recent developments in cloud computing have promisingly opened new opportunities to enterprises for a new transformation era. Implementation of cloud computing at inbound as well as outbound of enterprises facilitates the realization of modularity in every branches. While keeping the independent identities of modules, provision of a common platform brings about a collaborative framework for alternative modules, which can solve the problem of distributed planning and control in SCM.

Modularity in processes improves the performance of enterprises in terms of robust process design with higher flexibility and productivity (Shamsuzzoha & Helo, 2011). The complementary approach of modular processes, confronting additive manufacturing technology, links every specific source of variability in customers' demands to a particular segment of value chain processes (Walcher/Piller, 2012). Consequently, alternative requirements for meeting a customer demand can be satisfied through a proper recombination of process modules throughout a network with no need to redesign expensive ad hoc processes. This tailoring of solutions aimed at fulfilling individual demands gives rise to superior flexibility, operational efficiency, and cost reduction throughout enterprises and SNs. It holds true also for resource modularity that provides high flexibility in utilizing any type of resources in a dispersed as well as collaborative manner (Cao, Jing, & Wang, 2008; Roh et al., 2009; Zhou & Wu, 2010).

4. Cloud computing and integration

In order to realize the modern approach to integration of SNs and the recommended modularity's concept for the building-blocks of enterprises and SNs, cloud computing as a state-of-the-art technology seems quite practical. Alternative forms of cloud and the progressive development of each form, regarding various needs of current industries and prospective businesses, can positively comply with the integration of disturbed and heterogeneous entities by means of a cloud network. Once the cloud configures a virtual network, the entities of an industry from micro-scale (e.g. logistics objects) to macro-scale (network partners) can even move beyond passive modules, i.e. towards autonomous units with collaborative capabilities. In elaborating this merit, the fundamental of cloud computing has to be explained. Generally, cloud computing has several service and deployment models which can be employed for modular and autonomous systems. Some regular services are as follows (Van der Molen, 2010), but not limited to:

- Infrastructure-as-a-service (IaaS): to provide a large scale of the required hardware (e.g. in modular and distributed form) to install a stack of modular software on them or to realize distributed processors with no need to proliferate any processors (less technological problems).
- Platform-as-a-Service (PaaS): to provide a set of modular software, program languages, and hardware that can be combined to build a complete form of an applicable software, methods, and algorithms for modular processes and distributed (autonomous) entities.
- Software-as-a-Service (SaaS): to provide computational software required for individual modules in a remote and seamless way.

These main three service models, besides other potential services (XaaS), can positively cooperate to bring the concept of modular and autonomous entities in an SN closer to practice. Moreover, several deployment models of cloud can be imagined for logistics and production environments which are as below (Chandrasekaran, Muralidhar, & Dixit, 2013):

- Private cloud: this type is locally managed and is usually allocated to an organization (e.g. shop floor of a partner in an SN).
- Community cloud: this type covers several shared infrastructures between some organizations, e.g. in the form of small consortiums and collaborative networks.
- Public cloud: available for public sector or big industries, which can include customers into integrated SNs. It is offered and managed by a third-party organization professional in the cloud branch.
- Hybrid cloud: a fusion between different models (private, community, or public) by means of standard interfaces or portability, quite suitable for comprehensive SNI (from micro- to macro-scale).

Indeed, development of a domestic as well as global cloud can provide a large common platform with alternative modules of processes, software, virtual product parts, virtual resources, and virtual suppliers; all with compatible interfaces for being joined together to build new clusters of working packages. Even though for enriching the content of the cloud in terms of strengthening the exchange of know-how between collaborative enterprises and legal persons, configuration of a consortium (a temporal collaboration network) seems essential. Consequently, cloud computing in

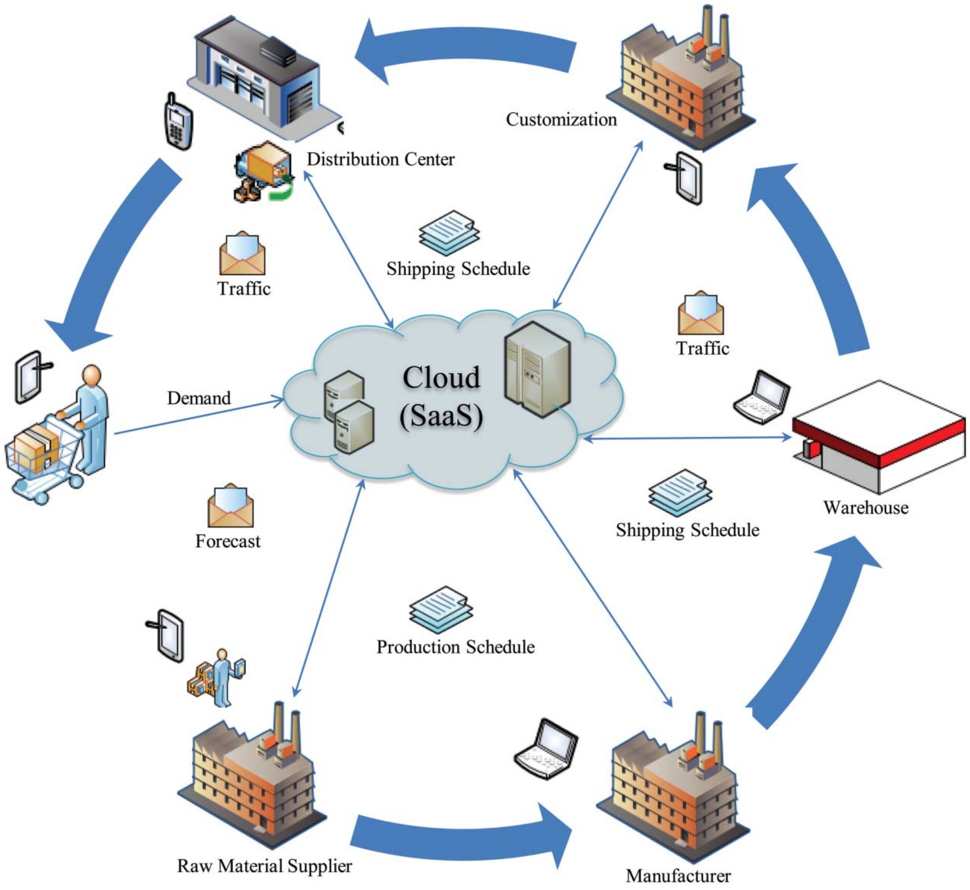

Figure 4. An exemplary collaborative network via cloud.

manufacturing environment provides a common resource platform for computational loads between all participants of a network that drastically reduces the cost of (enterprise resource planning) ERP systems, see for example Figure 4. In addition to the provision of common platforms for planning, cloud can help enterprises to compensate their scalability requirement for resources or software-modules in case of demand fluctuations. Therefore, this leads to a faster adjustment of resources in fulfilling fluctuating and unpredictable demands in a highly flexible configuration of networks. In this regard, some advantages of cloud computing used by partners and SNs are (Van der Molen, 2010): improved business agility to get applications up and run quicker, reduced capital expenditure, increased end-user productivity and collaboration that improve manageability, and reduced energy consumption that leads to less maintenance.

In general, the idea of cloud computing for SNI (Figure 5) is inspired by several current and prospective industrial requirements as well as new achievements in state of the art in cloud computing. These issues can mainly be summarized as follows:

- Narrow competition between international companies and the necessity of meeting highly customized demands of international customers.
- Deep interest for innovative products and production systems at superior flexible and agile enterprises/networks.
- High complexity of organizing and coordinating endeavors in big enterprises and SNs with modular systems (Figure 6).
- New developments in state-of-the-art ICT (e.g. autonomous entities, cloud computing) and the competent provided infrastructure by them.
- Facilitation of employing best practices from domestic and global experiences via connectivity and learning capability, which can be realized by new structured cloud.
- Profound desire for increasing productivity and efficiency of prospective enterprises and SNs in the form of new cooperative and collaborative networks to be facilitated by cloud computing and smart modules.
- Great academic encouragement for recognizing real-time material flow control and prompt changeability of processes in practice.

5. Control of modules in cloud

As stated before, increase in flexibility, derived from the large amount of modules, brings about a surge in

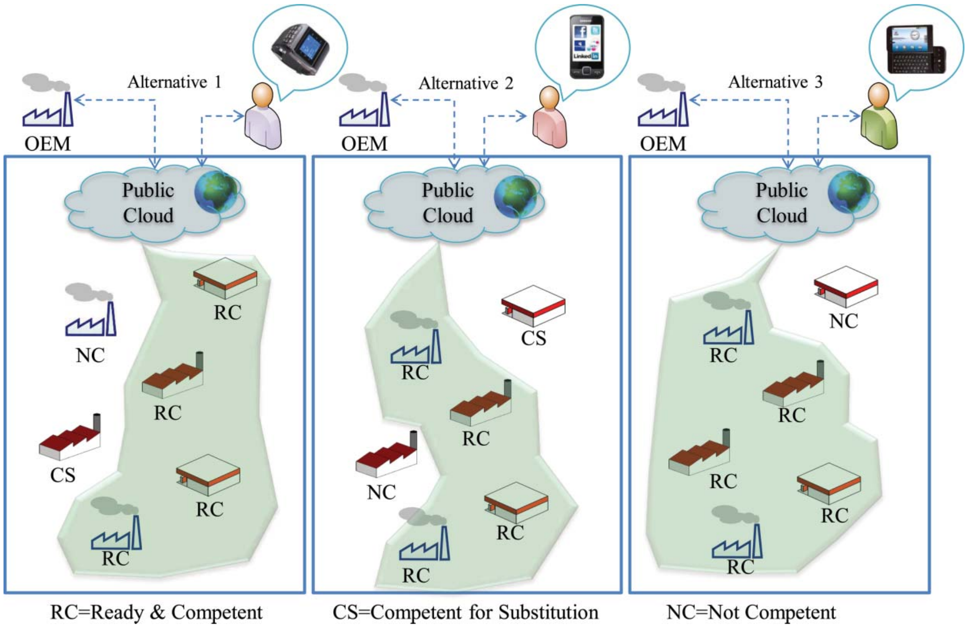

Figure 5. Modular supply network by means of cloud computing.

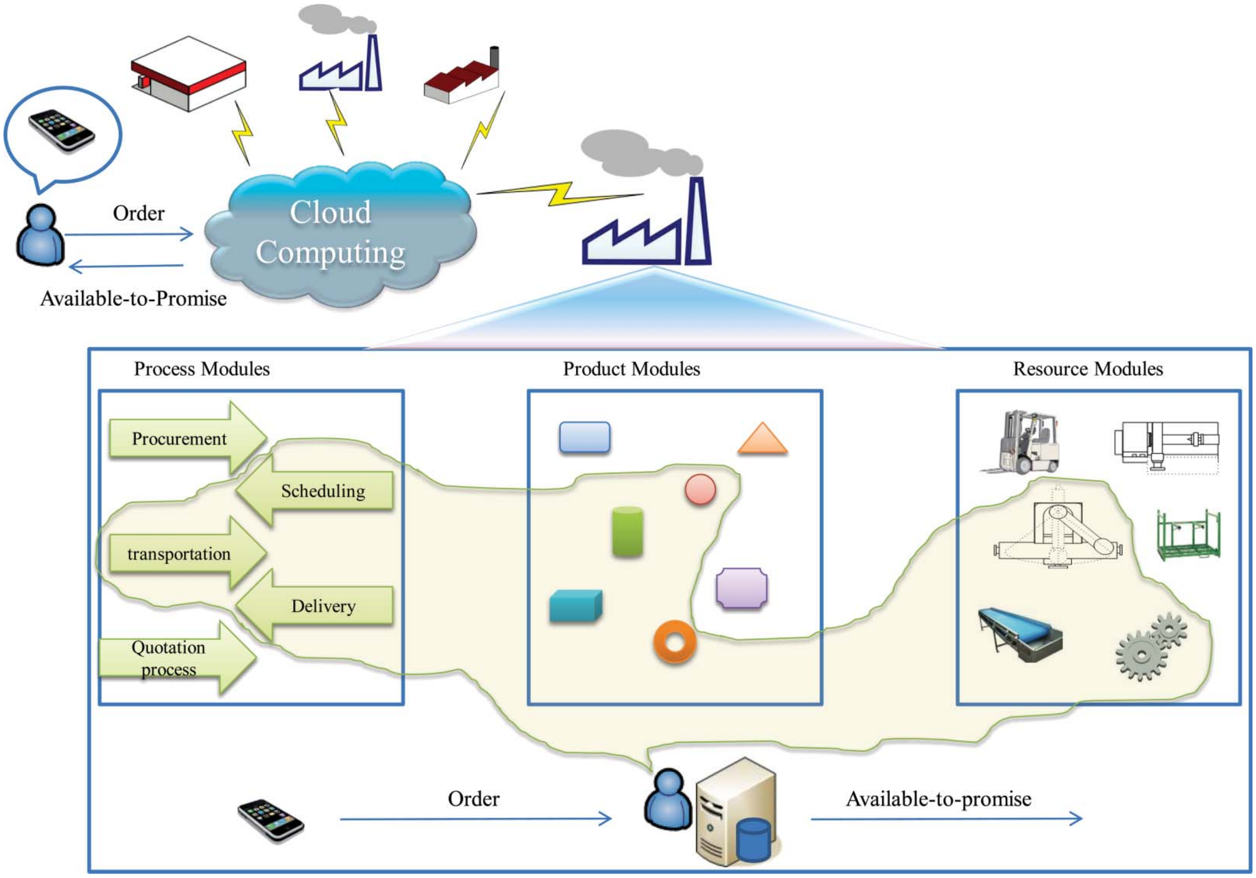

Figure 6. First alternative.

alignment's complexity of operations too. This major management challenge of enterprises in organizing their entities can be handled by means of state of the art in management and technology. In doing so, three main chronological (also as alternative) solutions can be imagined which provide a configuration/organization system for managing the multitude of modules (i.e. products, processes, and resources). Implementation of these alternatives in manufacturing enterprises and SNs can reasonably take place, thanks to the novelty of cloud. These solutions can stepwise be achieved in a modular manufacturing system as below:

- First: hierarchical, top-down, and central configuration system with predefined rules and awareness of every module's standard attribute and utility by the center.
- Second: hierarchical, bottom-up and top-down central configuration system with decentralized recommendations of local modules with their own capabilities to the centre.
- Third: heterarchical and decentralized configuration system with recommendations and negotiations of local modules based on equity and prompt clustering potentials to cover a variety of capabilities.

Realization of each of these alternatives depends on technological competencies and some internal/external issues of respective enterprises; among which include the degree of process- and product-modules' complexity of an enterprise and other supply members. The first alternative is the simplest and a conventional control technique to mobilize a configuration system for handling multitude modules, albeit with some limitations in the entire performance. These limitations comprise application of predefined rules and descriptions about each module and final products. This type of configuration system is able to manage a certain number of modules, in an offline manner, which aim at meeting a limited range of customized products, see Figure 6. This first alternative seems suitable for those SNs that have restricted scope of product variants with relatively simple and standard process-modules for supplying, manufacturing, and delivering. However, smart modules may assist the clustering procedure of respective process-, product-, and resource-modules in responding to a new arriving order.

On the other hand, enterprises with wide range of product customization can cover a large scope of customers. Thus, they need to cooperate with relatively large scope of SNs in order to procure and to deliver their materials and products. These interdependencies and cooperation with external players complicate the internal performances as well. Besides, process-, resource-, and product-modules need to be matched together to fulfill the final customer.

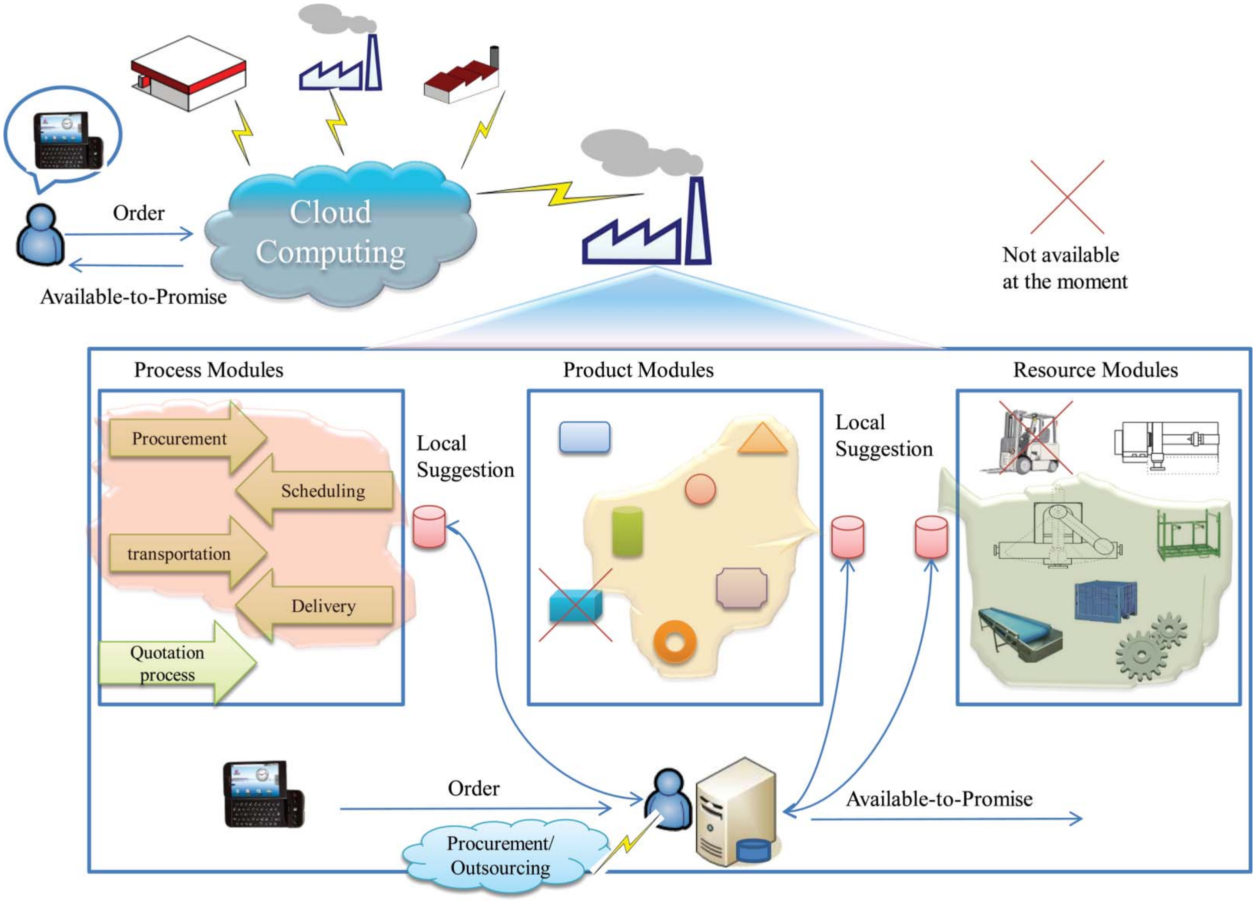

Figure 7. Second alternative.

This growth in performance complexity persuades enterprises to adopt new types of modular systems (second and third alternatives), which can provide more flexibility, higher productivity, and simpler functionality; this is all about time. Distributing the functional attributes of dispersed modules in an enterprise (or an SN) declines the load of a central organizing system to aggregation and matching of standardized functionalities of multitude modules, to comply with an order. In the second alternative, instead of preserving the standard functional attributes of each module with offline decision-making of the central system, the modules can offer their own capabilities in real-time. Once a new order comes, each module, regarding its design, location, current situation, list of capabilities, etc., informs its availability to the central (coordinating) system. Upon this information and the predefined aggregated description of modules, the central system can flexibly delimit the most effective cooperative clusters out of the available modules in fulfilling the respective arriving orders. The second alternative resembles the distributed control system (Hossain, Nelson, & Dasgupta, 2012) concerning the complexity of the central organizing system, see Figure 7.

The third alternative slightly varies from the second one. In this case, the configuration role of a central system is removed; instead this duty is transmitted to the dispersed intelligent modules. In other words, the modules need to be intelligent enough to distinguish their contributions to new orders and to be able to directly contact their complementary modules for configuring a competent cluster for specific tasks. This mission can be occurred based on negotiation of intelligent modules. However, it is not necessarily compelled to give intelligence to each single module. Some local and distributed modules may be connected to a monitoring module which can accomplish the intelligent decision-making, see Figure 8. Some benefits over the second alternative can be achieved by the new organizing structure in the third alternative, which necessitates new specifications of ICT. The third structure is defined to achieve decentralized control (Mayer, 2011) for multitude processes and modules, not controllable otherwise. However, implementation of this alternative has to be compromised against its current and prospective needs by industries and its profitability. Following are some advantages and requirements of the third alternative:

- Fully modular system with real-time and direct communication between concurrent modules.
- Fully decentralized control and contributions based on equilibrium.

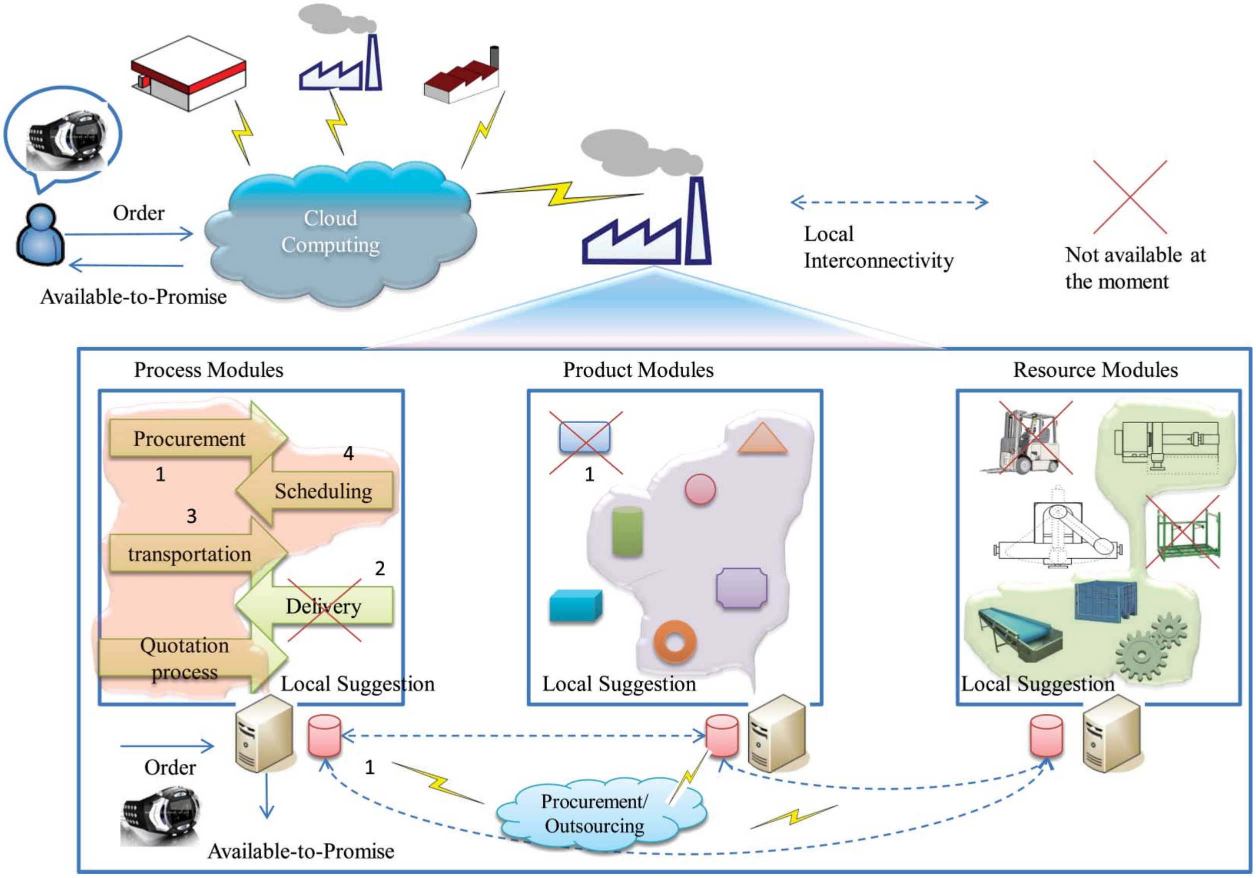

Figure 8. Third alternative with interconnected modules via monitoring modules.

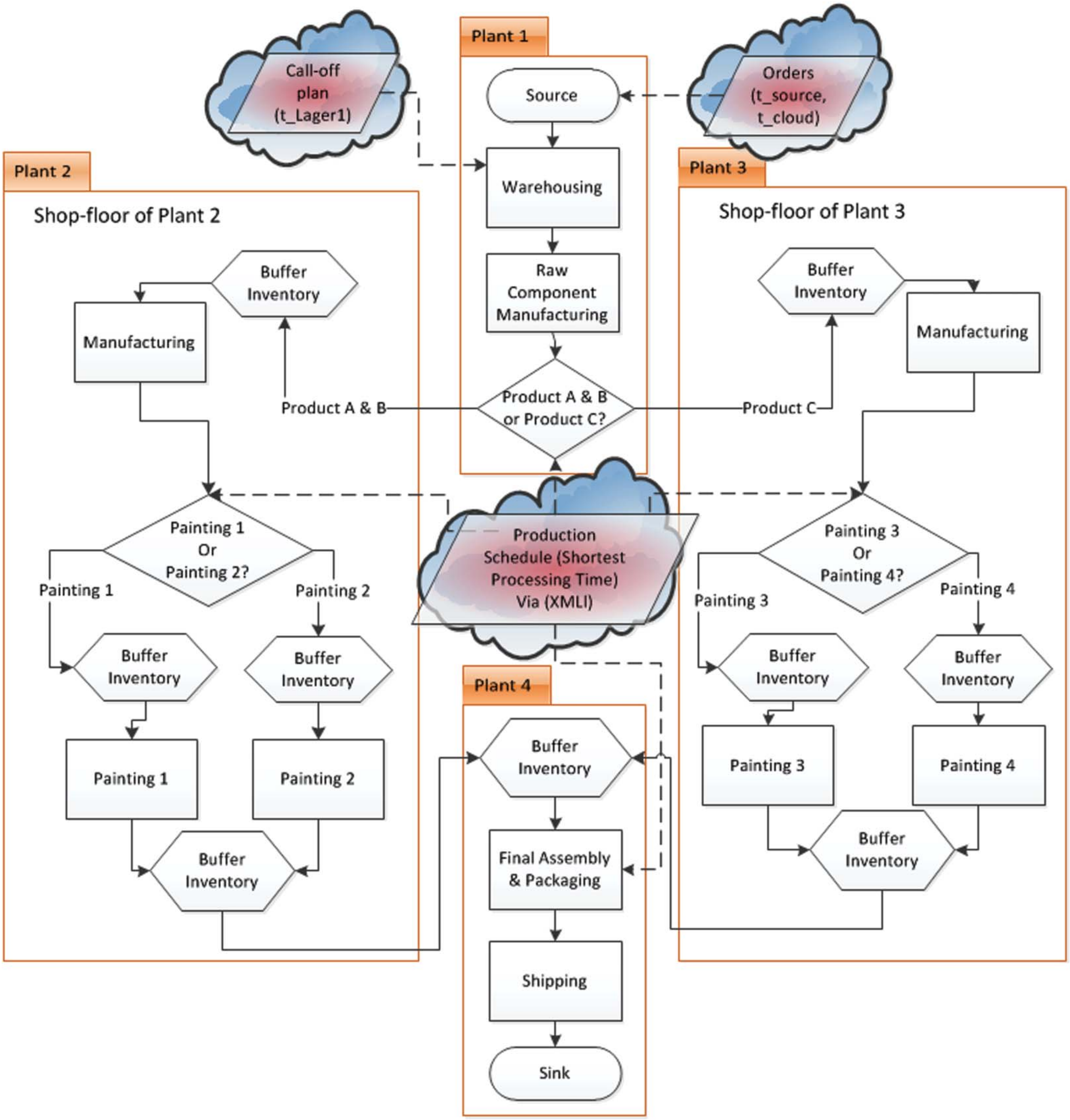

Figure 9. Throughputs per hour in experiments 1, 2, and 3.

- Fully flexible structure for temporal contribution and collaboration, based on current competency of inbound as well as outbound modules (SN).
- Continuous development in modules' capabilities by means of local learning as well as global expertise, supplied via cloud.
- Configuration of building-blocks (resembling the novelty of Lego) to form new innovative combinations and business structures, applicable through cloud.
- Realization of local decision-making by local customer-centric modules in a network.
- Exploitation of domestic and global know-how for local decision-making via cloud.
- Self-organizing modules (or monitoring modules) with intelligence and negotiation aptitudes.
- Reduction in computational loads for each individual intelligent module and assigning them to a private cloud.

6. Exemplary SN simulation

In order to experiment the performance of prospective SNs, a discrete-event simulation model is set up here that represents the employment of cloud computing to virtually integrate and optimize the processes of networks' partners. The developed scenario out of a very simple SN reflects the applicability of cloud in organizing the flow of standard modules throughout the network from the first source suppliers toward the customer side. In this experiment, the mission of planning and control of material flows has been accomplished by means of cloud-service as SaaS, which is totally extendable to PaaS and IaaS in future studies. Generally, this considered network is built out of four plants, i.e. a source plant, two parallel manufacturing plants, and an assembly plant as OEM. There are three modules (A, B, and C) of a final product, that every couple of the three module (i.e., A + B, B + C, C + A,) configures a final product. Eventually it ends up with three product alternatives. See Figure 9 for detailed information and material flows. As it is shown there, each plant in the network is connected to the cloud platform service (SaaS) to get information about the real demand changes and real-time planning and scheduling for material flow, see also Yang, Zhou, Sun, and Cruickshank (2013). This information exchange between the simulation model (in Plant Simulation) and the planning program base on JAVA takes place via the XML interface. The flow charts in Figure 10 represent the flow of material and information throughout the network in general.

In this simulation, cloud computing only assists the planning of material flow in a distributed but a centralized way, thanks to a common platform of SaaS. This special structure leads to favorable harmony between the network's members. The results of the simulation in Table 1 and Figure 10 are grouped in three experiments types as planning for: (1) just the source plant, (2) just OEM, and (3) the source and OEM simultaneously. This arrangement of cloud planning represents the usability of employing a virtually centralized planning platform in a distributed structure. The considered performance criteria for evaluating the network are average throughput time (Avg. TPT), standard deviation of TPT, min and max of TPT, and throughput (final product) per hour (TP/h) at the sink. Basically, the more the TP/h, the better performance or the less Avg. TPT the more favorable record is. The values of the metrics show that the best performance of the network in terms of all criteria is experiment 3, which reflects the concurrent application of cloud (SaaS) for material planning at plant 1 (source) and plant 4 (OEM). In this experiment type, in general, Avg. TPT is less than other experiments, TP/h is higher than others, and min TPT is relatively low. Experiment 1 reflects this application just at OEM and defines the moderated performance, whereas experiment 2 refers to employment of cloud just for the source plant and represents the worst performance. Indeed, the application of fully decentralized and distributed planning and scheduling systems in such networks that every agent can follow its own interest without any harmony in between may lead to the results of experiment 1 or 2; with worst performance record than the distributed while virtually centralized planning on the common cloud platform.

Table 1. Result of simulation in three experiment alternatives.

Module type	Avg. TPT (h)	stddev. TPT (h)	min. TPT (h)	max. TPT (h)	TP/h
Experiment 1					
A	244	78	5.2	386	3.75
B	244	152	4	659	4.36
C	249	146	3.22	680	2.96
Experiment 2					
A	245	157	0.2	590	1.12
B	277	198	3.02	582	1.00
C	118	67	0.3	267	1.00
Experiment 3					
A	252	147	0.2	468	5.00
B	109	42	0.3	157	4.33
C	191	109	1.1	390	3.31

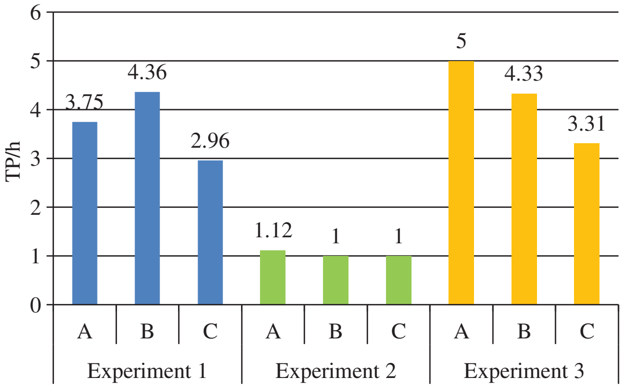

Figure 10. Material and information flow of the network scenario.

7. Conclusion and discussion

In summary, the contribution of this paper to the ongoing challenges of current and prospective SNs included four major aspects as: integration of SNs, modularity (in product, process, and resource), MC and MTU production strategy, and cloud computing as web-based services. It has been discussed that SNI mission is getting continuously complex, while its necessity has been justifying. Therefore, thanks to recent achievements in ICT and production technologies, new approaches for this importance had to be experimented. These include types of control and coordination of distributed and heterogeneous entities (modules) in networks.

Accordingly, among some potential alternatives (e.g. fully connected and coordinated SNs), this paper introduced a framework for complying with the production of individualized products in the turbulent global market by flexible, distributed, but integrated SNs. This framework is established based on three major pillars as modularity, customization with MTU strategy, and cloud computing, which integrate the entire body of an SN, including customers. This novelty gives the opportunity to distributed members of an SN to properly cooperate and collaborate with each other, so that their independency is kept, whilst being automatically coordinated at the cloud platform. The type of coordination and control of these members is partially discussed in this paper; nonetheless, more deep elaborations are required. However, the advantage of the introduced framework encompasses: capability of promptly meeting market changes as well as quickly reconfiguring the performance structure of an enterprise/SN (by means of modularity, traceability, and upgradability), reduction of investment in information systems, and competent coordination of all data exchange thanks to the common platform of the cloud. Moreover, the simulation has proven that the application of modular design can be led to a compatible platform for employing cloud as a distributed as well as virtual planning and coordinating mean. The results showed that the more connected to the cloud, the better performance of the network can be achieved.

As further works, the authors recommend a more precise and extended simulation of alternative SNs with application of cloud computing not just as SaaS, but also in other branches of this leveraging technology. Exploration of different aspects of cloud (e.g. cloud manufacturing) in assisting the competitiveness of SNs is a future research challenge for the authors. Alternative control approaches for coordinating heterogeneous modules of a network has to be elaborated in a technical and mathematical way. Moreover, the compatibility of new approaches in production strategies (e.g. MTU) has to be justified in practical case studies. Modularity and its alternatives, including all features of production, are to be studied in later works.

References

Abdelkafi, N. (2008). *Variety induced complexity in mass customization: concepts and management* (Vol. 7). Berlin: Erich Schmidt Verlag GmbH & Co.

Ahmad, S., Schroeder, R. G., & Mallick, D. N. (2010). The relationship among modularity, functional coordination, and mass customization: Implications for competitiveness. *European Journal of Innovation Management*, *13*(1), 46–61.

Bask, A., Lipponen, M., Rajahonka, M., & Tinnilä, M. (2010). The concept of modularity: Diffusion from manufacturing to service production. *Journal of Manufacturing Technology Management*, *21*(3), 355–375.

Bocconcelli, R., & Tunisini, A. (2009). Value creation through product modularity: The user's perspective. In H. Hakansson, A. Waluszewski, F. Prenkert, & E. Baraldi (Eds.), *Use of Science and Technology in Business: Exploring the Impact of Using Activity for Systems, Organizations, and People*, International Business and Management Series (Vol. 25, pp. 165–182). Bingley: Emerald.

Bosona, T. G., & Gebresenbet, G. (2011). Cluster building and logistics network integration of local food supply chain. *Biosystems Engineering*, *108*(4), 293–302.

Brun, A., & Zorzini, M. (2009). Evaluation of product customization strategies through modularization and postponement. *International Journal of Production Economics*, *120*(1), 205–220.

Cao, W.-q., Jing, S.-h., & Wang, X.-h (2008, June 3–5). *Research on manufacturing execution system for cement industry*. 3rd IEEE Conference on Industrial Electronics and Applications, ICIEA 2008, Singapore, pp. 1614–1618. doi: 10.1109/ICIEA.2008.4582792

Chandrasekaran, M., Muralidhar, M., & Dixit, U. (2013, March). Online optimization of multipass machining based on cloud computing. *The International Journal of Advanced Manufacturing Technology*, 65(1–4), 239–250.

Che, Z.-H., Chiang, T.-A., & Kuo, Y.-C. (2012). Multi-echelon reverse supply chain network design with specified returns using particle swarm optimization. *International Journal of Innovative Computing, Information and Control*, *8*(10(A)), 6719–6731.

Chen, H., Daugherty, P. J., & Landry, T. D. (2011). Supply chain process integration: A theoretical framework. *Journal of Business Logistics*, *30*(2), 27–46.

Cheung, C. F., Cheung, C. M., & Kwok, S. K. (2012). A knowledge-based customization system for supply chain integration. *Expert Systems with Applications*, *39*(4), 3906–3924.

Da Cunha, C., Agard, B., & Kusiak, A. (2007). Design for cost: Module-based mass customization. *IEEE Transactions on Automation Science and Engineering, 4*(3), 350–359.

Danese, P., Romano, P., & Formentini, M. (2013). The impact of supply chain integration on responsiveness: The moderating effect of using an international supplier network. *Transportation Research Part E: Logistics and Transportation Review*, *49*(1), 125–140.

Davis, S. M. (1989). From future perfect: Mass customizing. *Planning Review*, *17*(2), 16–21.

Flynn, B. B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of Operations Management*, *28*(1), 58–71.

Fogliatto, F. S., da Silveira, G. J. C., & Borenstein, D. (2012). The mass customization decade: An updated review of the literature. *International Journal of Production Economics*, *138*(1), 14–25.

Hossain, S. G. M., Nelson, C. A., & Dasgupta, P. (2012). Hardware design and testing of ModRED: A modular self-reconfigurable robot system. *Advances in Reconfigurable Mechanisms and Robots, I*, 515–523.

Hribernik, K. A., Rabe, L., Thoben, K.-D., & Schumacher, J. (2006). The product avatar as a product-instance-centric information management concept. *International Journal of Product Lifecycle Management*, *1*(4), 367–379.

Jacobs, M., Droge, C., Vickery, S. K., & Calantone, R. (2011). Product and process modularity's effects on manufacturing agility and firm growth performance. *Journal of Product Innovation Management*, *28*(1), 123–137.

Jose, A., & Tollenaere, M. (2005). Modular and platform methods for product family design: Literature analysis. *Journal of Intelligent Manufacturing*, *16*(3), 371–390.

Koufteros, X., Vonderembse, M., & Jayaram, J. (2005, February). Internal and external integration for product development: The contingency effects of uncertainty, equivocality, and platform strategy. *Decision Sciences*, *36*(1), 97–133.

Kumar, A. (2004). Mass customization: Metrics and modularity. *International Journal of Flexible Manufacturing Systems*, *16*(4), 287–311.

Li, Y.-C., & Liao, H.-C. (2012). The optimal parameter design for a blood supply chain system by the Taguchi method. *International Journal of Innovative Computing, Information and Control*, *8*(11), 7697–7712.

Mayer, S. (2011). *Development of a completely decentralized control system for modular continuous conveyors*. Norderstedt, Germany: GRIN Verlag.

Mikkola, J. H. (2007). Management of product architecture modularity for mass customization: Modeling and theoretical considerations. *IEEE Transactions on Engineering Management, 54*(1), 57–69.

Pereira, J. V. (2009). The new supply chain's frontier: Information management. *International Journal of Information Management*, *29*(5), 372–379.

Reijers, H., & Mendling, J. (2008). Modularity in process models: Review and effects. In: M. Dumas, M. Reichert, & M.-C. Shan (Eds.), *Proceedings of the 6th international Conference on Business Process Management, Milan, Italy* (pp. 20–35) (Lecture Notes in Computer Science, Vol. 5240). Berlin: Springer-Verlag.

Roh, S.-g., Yang, K. W., Park, J. H., Moon, H., Kim, H.-S, Lee, H., & Choi, H. R. (2009). A modularized personal robot DRP I: Design and implementation. *IEEE Transactions on Robotics*, *25*(2), 414–425. doi: 10.1109/TRO.2009.2014499

Salvador, F., De Holan, P. M., & Piller, F. (2009). Cracking the code of mass customization. *MIT Sloan Management Review*, *50*(3), 71–78.

Schön, O. (2012). Business model modularity – a way to gain strategic flexibility? *Controlling & Management*, *56*, 73–78.

Shamsuzzoha, A. H. M., & Helo, P. T. (2011). Information dependencies within product architecture: Prospects of complexity reduction. *Journal of Manufacturing Technology Management*, *22*(3), 314–329.

Smith, S., Smith, G. C., Jiao, R., & Chu, C.-H. (2012). Mass customization in the product life cycle. *Journal of Intelligent Manufacturing*, 1–9.

Thoben, K.-D., & Jagdev, H. S. (2001). Typological issues in enterprise networks. *Production Planning & Control*, *12*(5), 421–436.

Tsao, Y.-C., & Su, P.-Y. (2012). A dual-channel supply chain model under price and warranty competition. *International Journal of Innovative Computing, Information and Control*, *8*(3(B)), 2125–2135.

Tsukune, H., Tsukamoto, M., Matsushita, T., Tomita, F., Okada, K., Ogasawara, T., . . . Yuba, T. (1993). Modular manufacturing. *Journal of Intelligent Manufacturing*, *4*(2), 163–181.

Van der Molen, F. (2010). *Get ready for cloud computing: A comprehensive guide to virtualization and cloud computing*. Zaltbommel: Van Haren Publishing.

Walcher/Piller. (2012). *An international benchmark study on mass customizationand personalization in consumer e-commerce*. A study by MIT Smart Customzation Group, RWTH Aachen University Technology & Innovation Management Group, Salzburg University School of Design & Product Management. Retrieved from www.mc-500.com

Winkler, H. (2009). How to improve supply chain flexibility using strategic supply chain networks. *Logistics Research*, *1*(1), 15–25.

Wong, H., & Lesmono, D. (2013, July). On the evaluation of product customization strategies in a vertically differentiated market. *International Journal of Production Economics*, *144*(1), 105–117. doi: 10.1016/j.ijpe.2013.01.023

Xia, N., & Rajagopalan, S. (2009). Standard vs. custom products: Variety, lead time, and price competition. *Marketing Science*, *28*(5), 887–900.

Yang, Y., Zhou, Y., Sun, Z., & Cruickshank, H. (2013). Heuristic scheduling algorithms for allocation of virtualized network and computing resources. *Journal of Software Engineering and Applications*, *6*, 1–13.

Ye, Y., Yang, D., Jiang, Z., & Tong, L. (2008). An ontology-based architecture for implementing semantic integration of supply chain management. *International Journal of Computer Integrated Manufacturing*, *21*(1), 1–18.

Zhou, K. Z., & Wu, F. (2010). Tehnological capability, strategic flexibility, and product innovation. *Strategic Management Journal*, *31*(5), 547–561.