Methodology for non-hierarchical collaboration networks for complex products manufacturing

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Abstract
To successfully compete in the market, European SMEs will have to adopt new business models and establish dynamic and non-hierarchical networks, assuring quick response, fast time to market, differentiated offerings and competitive prices. Sustainability will be found in high-variety and low-volume businesses, related with complex products design and manufacturing. This paper presents a Methodology concept, developed by the European project Net-Challenge, supporting SMEs in building and operating non-hierarchical business networks for complex products manufacturing with Engineer-To-Order (ETO) or Assemble-To-Order (ATO) strategies.

Keywords
Collaboration, non-hierarchical networks, production networks, methodology

1 Introduction
To compete with large companies European SMEs have to implement advanced forms of collaboration. Sustainability will be found in high-variety and low-volume businesses, related with complex products design and manufacturing [Manufuture, 2006]. Since SMEs are often too small to fulfil independently the customer needs, when a business opportunity arises they need to form agile partnerships to specify the product, collaborate with partners to set-up the price and the lead-time to make a quotation.

In most of the scenarios related with complex and customized products manufacturing, and also in the case networks analysed, business opportunities can lead to Engineer-To-Order (ETO) or Assemble-To-Order (ATO) strategies, with collaboration needs in activities like design, component manufacturing, finishing and transportation. The ATO approach is used for customization scenarios and the importance of defining the product platform is discussed. In case of ETO strategy the development of one-of-a-kind product is the main focus. However, specific methods and tools to support the management of these non-hierarchical networks for complex products manufacturing in ETO or ATO scenarios are missing.

This paper presents a methodology concept supporting SMEs to foster collaboration, by taking into account market and product related trends and the analysis of three case networks. The well known concepts for managing Virtual Organisations Breeding Environments (VBE) [Camarinha-Matos, et al. 2005] are extended to address the requirements of complex customized products manufactured for single customer orders or market driven innovations.

In this context, the goal of the Net-Challenge European project [Ref.: FP7-CP-FP229278-2] is to design and develop a set of support tools to help SMEs implement new business models and establish dynamic and non-hierarchical business networks for complex products manufacturing.
The proposed supporting tools will help SMEs in the formation and operation of such networks, including a Methodology that provides the conceptual and methodological support; a business processes reference model and relevant IT decision support tools. This research paper presents initial results of the project, related with the Net-Challenge Methodology.

The paper is organized as follows: Section 2 outlines the existing theories and work related with the methodology for the creation and operation of ETO and ATO non-hierarchical collaborative networks. The general requirements and problem definition is presented in Section 3, while Section 4 discusses the overall findings and the main conclusions are presented in Section 5.

2 Relation with Existing Theories and Work

In today’s global markets, business collaboration is emerging in decentralized and dynamic forms instead of former static hierarchical networks and value chains [Camarinha-Matos, et al. 2005]. A decentralized and comparatively more flexible collaborative network, where no partner assumes a leading role that controls the network and settles the operational rules, is commonly known as non-hierarchical network. These networks allow the sharing of resources, production rates, earnings, market information, risks etc. Although the needs of non-hierarchical collaboration among SMEs are quite high, research on this growing field is still very limited [Ivanov, et al. 2006]. Several researchers have tackled the design of methodologies for collaborative networks management [Camarinha-Matos 2005, Camarinha-Matos, et al. 2009, Ivanov, et al. 2004, 2005, Ivanov 2006], but they address more generic scenarios and don’t cover the specificities of complex products manufacturing.

Growing demands for complex and personalized products suggest the implementation of ETO and ATO production strategies among SMEs, forcing them to explore supportive tools or methodologies with a view to reduce their long lead time and improve their margins. The problem for longer lead time has direct or indirect causes within the design phase, in which scarcity of resources and inefficient or ineffective information sharing is involved [Pandit and Zhu, 2007; Hicks and McGovern, 2009]. In such an environment, collaboration among SMEs in a non hierarchical structure could contribute to reduce the most common problems associated with the ETO and ATO production processes such as lead times, delivery dates, reworks, material wastage etc. Business collaboration among potential partners supports the generation, analysis, sharing and reuse of common design knowledge as required by ETO and ATO business processes, which also provides the evaluation of design alternatives through collaborating information systems. In this context ATO is seen as an approach to tackle the development and production of customized products.

In literature, there is a lack of approach, methodology or framework for the collaborative development of both ETO and ATO networks [Peters et al. 1999, Rahim and Baksh 2003]. The collaborative business environment among SMEs might fill this gap through providing better supporting tools and atmosphere in their customized product development phases. ETO and ATO production processes should be supported by new product development framework that can indicate clear direction of design goals, has easy to follow approach, aids in design documentation process, presents key characteristics of the design process, facilitates communication among various partners in the production network, is demonstrating simple and practical plan for implementation, is serving as a control mechanism to include concurrent engineering tools and also includes human interface collaboration tool [Rahim and Baksh 2003].

A collaborative business network implies communication and information exchange for mutual benefit (networking), but also that coordination at various levels and joint work and responsibility occur among participating SMEs [Denise 1999, Himmelman 2001, Pollard 2005]. Other forms of collaboration such as virtual enterprise (VE), virtual organization (VO), virtual organization breeding environment (VBE) etc. can be found in the literature. For instance, VE and VO represent a temporary alliance among organizations to achieve specific missions or
goals, whereas VBE considers a strategic association of organizations with long term cooperation agreement and adoption of common operating principles and infrastructures with the main goal of enhancing their collaboration opportunities [Camarinha-Matos and Afsarmanesh 2008]. These collaborations are achieved through both hierarchical with higher controls over collaborative partners and non-hierarchical where partners enjoy similar level of control on each other.

The research in management of non-hierarchical collaboration networks is multi-disciplinary and cross linked. In this article, we have given specific attention to the procedural steps or methodology for creating and operating non-hierarchical collaboration networks of SMEs, producing complex, low volume and high variety products. Business networks life-cycle is an important issue, however, few related information could be found in literature [Schutjens and Stam 2003, Nayak, et al. 2001, Koka, et al. 2006, Ming and Lu 2003]. Ahlström-Söderling [2003] proposed a change model for business networks, where three phases of life-cycle exists namely; ‘formative phase’ that clustered the collaboration among business partners, ‘normative phase’ that secures the collaborative networks by integrating partners and ‘integrative phase’ where partners mutually cooperate for further development. The most complete research work identifies 3 main stages: creation, operation and dissolution [Camarinha, et al. 2008]. These three stages are the fundamental needs for co-operating in collaborative networks, where the success of the networks life cycles is depending on their mutual integration. For a decentralized decision making process such as non-hierarchical business networks, SMEs need to integrate and manage their partners network to achieve the target business goals.

Romero and Molina [2009] present a toolkit for virtual organization breeding environments (VBE). They divide the VBE lifecycle into initiation and recruiting, foundation, operation, evaluation, metamorphosis and dissolution phases. Inside the VBE Virtual Organizations are planned, created, operated and dissolved [Romero and Molina 2009]. During VBE initiation and recruiting environmental analysis, emerged need analysis and strategic planning are carried out. After planning process the strategic implementation phase starts. Next phase is the foundation of VBE including the following: ICT-solution set-up, governance structure establishment and the new members are analyzed. During VBE operation and evolution phase the VBE actors are managed, virtual organization creation and management iterates and VBE general management activities are carried out. The model was built during ECOLEAD European project and the implemented applications were small components supporting one single task in the main phase.

The challenge of this study is designing a simple and practical Methodology to be used by SME networks and to cope with the requirements of complex and customized products.

3 Requirements and problem definition

The research approach was based on the analysis of three case business networks, selected from different industrial sectors to maximise the applicability of the results. The selected industrial case networks come from the sectors Textile and Apparel (considering application of wearable technologies), machine tools and customized shoes. For each product value chain two companies (key members of their respective business networks) were considered, and their complete value chains were analysed. The analysis was divided on two levels: the analysis of each individual company and the analysis of the case business networks in which those companies were participating. For each case company products, markets, strategies, operations and networking practices were analysed. Then the complete value chains for the three case networks were analysed. This was done by interviewing key persons in the selected companies and some of their business partners.

On a second phase future business scenarios were defined, where higher collaboration levels were envisaged within the case networks. From the analysis of the companies, networks and scenarios, requirements were derived for the Net-Challenge Methodology. The greatest
challenge for the case companies is to compete based on short lead-times producing complex products in small batches or even customized products, which is a very common scenario for European SMEs. To meet the market requirements the traditional subcontracting is not enough. The requirements from the end-customers need to be solved in a team of trained partners who are agile and flexible enough to compete with quality, lead time and differentiated offerings, instead of price.

The case companies focus on complex products, with significant customer-oriented features or a large number of components. Before manufacturing, these products require complex engineering and deep understanding about the customers’ requirements. Some of the case companies are manufacturing personalized products, following the customer’s requirements and selections. For instance, a shoe manufacturer is offering personalized shoes, where personalized parameters from the potential customers such as size of the foot, heel, outsole, insole etc. are measured. After collecting the required measures from the customer, information is shared among potential partners in order to manufacture the final product according to the customer requirements.

In these scenarios there are strong needs for customer oriented design and engineering, where the information for product and process design, production planning and scheduling/routing are shared among partners. In order to manage the interaction among partners, the case companies usually use frequently phone discussions, faxes and email conversations. Currently, the interactions between customers and partners are bilateral and the information that is collected is difficult to share with the others. There is also a lot of tacit knowledge about the products and the manufacturing processes that needs to be shared. General requirements for promoting networking, knowledge sharing and trust were identified, together with specific requirements to assure technical qualification of critical partners.

The research problem was to define a Methodology providing a practical and phased approach to support SME’s in how to create and operate non-hierarchical networks for complex products manufacturing. The proposed Methodology develops further the VO creation and management concepts from previous research, with special focus on how to adjust the network for collaborative design and manufacturing of complex and customized products.

In this study a special attention is given to how the two manufacturing approaches ATO and ETO effect on the VO formation and operation. The specialities of networks for ETO (one-of-a-kind products) and ATO (customization scenarios) are considered in this study because of its importance for the case networks and for European SMEs at large.

Virtual organisations are based on business opportunities that can be customer order or innovation driven. In case of ETO production the product is designed using customer requirements and the knowledge of the partners. In ATO the VO is created for designing a product platform and responding to different customer orders by configuring the product. During the design phase also the manufacturing partners should be involved to define optimal solutions and enable design for manufacturing.

4 The proposed Methodology

The Methodology proposes two main levels (as presented in Figure 1) related with the life-cycle of: (1) the Business Community (BC) and (2) temporary Virtual Organisations (VOs). Each level of the Methodology is divided into self-explanatory phases to support the management of Business Communities and VOs. In order to be successful the methodology must be simple, efficient and easy to use for the SMEs.

The level related with the management of the Business Community (BC) includes Build and Qualify phases as depicted in Figure 1. In most cases the Business Community is built in a certain geographical area or to support a certain business area. The Business Community is a long lasting network where trust can be built and communication streamlined, supporting the fast and efficient creation of partnerships. This Business Community concept can be included in the
Virtual Organisation Breeding Environment (VBE) concept [Camarinha-Matos, et al. 2005]. The use the Business Community name instead VBE facilitated the communication with the case companies. In the Build phase the Business Community is created, developed and managed. The BC mission, business and governance model and operational rules are defined, networking and trust promoted.

The Qualification of business partners was considered necessary for some critical operations and aims to assure the defined requirements for critical operations and its improvement over time.

![Methodology high-level structure](image)

A set of partners Form a Virtual Organisation to fulfill a specific business opportunity. During the Form phase, the partners collaborate to specify the product, find a solution for the customer needs and set up a price and lead-time to manufacture the production batch. There are common tools to support the Operate phase: collaborative planning, monitoring, event and performance management. The lessons learned during the Form and Operate are transferred to the business community level during a formal Dissolve phase. The results are stored and the performance of each of the partners is later available at the BC level.

### 4.1 Approach to Formation and Operation for complex products

The Form and Operate Phases are presented in more detail, because they are the ones where collaborative networks for complex products manufacturing present more specific requirements. Because of the differences in the timing for involving the customer and the structuring of activities in the scenarios for customized products and one-of-a-kind products, two different approaches are defined based on ATO and ETO manufacturing strategies.

Table 1 distinguishes the basic differences between ATO and ETO strategies which influenced the development of the Methodology concept. The Form phase in ATO focus the creation of a product platform including shared knowledge from partners’ capabilities whereas, the Form phase in ETO context includes the initial design and quotation.

According to the developed methodology concept, the main difference between ETO and ATO scenarios is that in ATO a platform is designed to allow the product customization during Operate, whereas in ETO the focus is in one-of-a-kind production. The platform enables the customers to specify their needs based on the parameters and options available (customization).
The routing and the bill-of-material (BOM) are generated automatically based on the customer selections.

In case of ETO manufacturing the role for Form phase is to define the initial product concept for quotation and select the partners to calculate the price and lead time. The major engineering process will be carried out during Operate phase. Only very preliminary BOM is defined in order to quote the product to the customer.

In this context it is defined the role of a Broker, normally assumed by the organisation(s) that identified the Business Opportunity, and is responsible for the formation of the VO and for coordination the VO operation and dissolution.

<table>
<thead>
<tr>
<th>Collaboration phase</th>
<th>Manufacturing strategy</th>
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<tbody>
<tr>
<td>Form</td>
<td>Assembly-to-order (ATO)</td>
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<tr>
<td></td>
<td>Market driven</td>
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<tr>
<td></td>
<td>Customized production</td>
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<td>Collaborative innovation</td>
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<td>Collaborative design</td>
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<td>Partner selection by open bidding</td>
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<td>Product platform as result</td>
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<tr>
<td>Operate</td>
<td>VO will be a subset from the VO during form</td>
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<td></td>
<td>Variant definition (BOM, price, VO partners)</td>
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<td></td>
<td>Quotation and order confirmation</td>
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<td></td>
<td>Collaborate production monitoring</td>
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<td>Event monitoring</td>
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Table 1: The differences between ETO and ATO

4.1.1 Formation of a Virtual Organisation

(a) In case of ETO: During the Form phase the Virtual Organisation (VO) is created, including the selection of its members. A group of partners decide to collaborate in order to develop and/or produce a product or a collection of products. Given a business opportunity identified in the market, the objective of this phase of the methodology is to support the partner’s selection to respond to that specific business opportunity. The most important step during creation of a VO is the choice of the partners. In case of non-hierarchical networks, partner selection can be based on collaborative and reciprocal evaluation made within the BCs during previous activities. Previous studies define the following objectives for the VO Formation: collaborative opportunity (CO) identification, CO characterization, VO rough planning and partner search and selection (Romero & Molina 2009). However in case of one-of-a-kind ETO production a high level design is made to support the quotation. The idea of high level design is to create a rough plan and cost calculation. The VO Formation is done to create a quotation and the Form phase will end up by signing VO contract and customer contract (Figure 2). The quotation process is iterative; the partners are involved to define an optimal solution for the customer and to estimate the costs and schedules without spending too much effort. Some case networks are Forming Virtual Organisations to produce samples. The samples production involves partly the same partners but has to involve fewer resources.

(b) In Case of ATO: Assembly-To-Order manufacturing strategy is used in customization scenarios, where customers order products and services by selecting pre-defined options and components. There is a need to create a Virtual Organisation to set up a product platform to guide and fasten the product specification process and improve the variant cost-efficiency and quality (Figure 3).
Forming the platform is a collaborative process. The broker creates the backbone of the solution by defining the concept. The collaborative partners might propose their components to be added to the model to fulfill special customer needs. The broker shares the developing platform with VO partners and after specifying features (like water resistant) the partners can propose technical solutions to satisfy the request. White spots, define components that may be defined during the Operate Phase, and are defined for increased flexibility (functionality and costs are defined in Form). It is implemented only the level of detail of the platform design which is necessary for the selection of partners and to estimate the costs and sharing the benefits. The VO partners act as an internal client deciding if the Operations should be implemented or not.

4.1.2 Collaboratively operate the virtual organisation

The Operate Phase of the Methodology is related with the execution of the planned operations to respond to a specific market opportunity.
(a) **In Case of ETO:** the detailed product engineering and planning are carried out in the Operation phase. After releasing the detailed planning, execution starts and the status is monitored and updated accordingly. Possible solution(s) for unforeseen events are negotiated (Figure 4).

![Figure 4: Virtual Organisation Operation in case of ETO manufacturing](image)

(b) **In Case of ATO:** The first step of Operate is the detailed design of the product platform, including the definition of the detailed BOM and rules for price calculation. Each customer order for the business opportunity is managed though a single iteration of the second part of the Operate phase. The product is configured based on the specification received from the customer as displayed in Figure 5.

![Figure 5: Virtual Organisation Operation in case of ATO manufacturing](image)

The price of the configured product is calculated and the detailed planning defined. If the customer accepts the quotation (price and due date) and confirms the order, the order is deployed to all partners otherwise; the customer can define new requirements and reconfigure the product.
or cancel the process. After having the confirmed order, it is then released for the subsequent phases of execution, monitoring and event management, with similar approach to ETO.

5 Conclusion

The proposed methodology defines the guidelines for SMEs who want to set up and manage non-hierarchical business networks for complex products manufacturing, following ETO and/or ATO strategies. The methodology for manufacturing of complex, custom made or customized products required further development in relation to previous work [Camarinha-Matos, et al. 2009]. The overall framework had to be specialized based on the specific manufacturing approaches defined as ETO and ATO.

For customized products it is proposed an ATO production strategy, based on the definition of a product platform (with the possibility to have white spots that may be specified and selected in response to specific customer requirements and preferences). In the ATO production strategy, the VO firstly needs to develop a product platform from which a stream of product variants can be configured and produced.

In case of one-of-a-kind products an ETO production strategy is proposed. In both scenarios, it is crucial not to spend too much effort and time during the formation of the VO. After receiving the customer order, detailed design is done with the collaboration of the VO partners.

The proposed methodology was iterated and improved after considering various requirements from three different case business networks. From the presented approach SMEs can more easily create and manage their Virtual Organisations to deliver one-of-a-kind products or implement customization strategies.

This methodology will be part of the Net-Challenge project framework, which includes also a business processes reference model and relevant ICT decision support tools. The complete result of the methodology and other upcoming phases will be later available for the benefit of SMEs as a whole.

Acknowledgement

The authors would like to acknowledge the co-funding of the European Commission within NMP priority of the Seventh RTD Framework Programme (2007-13) for the Net Challenge project (Innovative Networks of SMEs for Complex Products Manufacturing), Ref. CP-FP 229287-2. The authors also extend their acknowledgments to the anonymous reviewers for their helpful comments and support.

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