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A Method for Facilitating the Design of Industry 4.0 Collaborations and its Application in the Aerospace Sector

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Abstract

Industry 4.0 envisions quick formation of manufacturing supply chains to ensure rapid reaction to new product requirements and configurations. This paper proposes a method for facilitating the design of collaborative teams which can implement sections of these supply chains by responding to invitations to tender by a manufacturer. The method includes five core design tasks which are applied recursively by partners to construct a collaboration model – (1) decomposing manufacturing goals, (2) team formation to tackle goals, (3) operationalizing goals into manufacturing processes, (4) decomposing processes and (5) defining execution workflows. The application of the method is shown using a case study from the aerospace industry with evidence of its utility in speeding-up collaborations.

Keywords: Collaboration design; Industry 4.0; Aerospace

1. Introduction

Industry 4.0-enabled transformations of supply chains through digitalization and increased collaboration activities inside and outside of companies (Arnold et al., 2016) bring new opportunities for small and medium-sized enterprises (SMEs) to collaborate in searching for, bidding for and executing manufacturing contracts. For such collaborations to happen with the necessary speed and agility, tools to support formation of collaborations are needed. Using such tools, companies can share their capabilities and excess capacities on electronic marketplaces (Cisneros-Cabrera et al., 2017) and coordinate their activities in bidding for new contracts and executing them. At present this is restricted due to several inter-firm barriers preventing collaborations between suppliers and between them and large manufacturing customers (Kazantsev et al. 2018). To enable efficient formation and coordination of supply networks, this paper proposes a *collaboration design method* (CDM) incorporating key Industry 4.0 principles such as decentralization, modularity, service-orientation, inter-operability, real-time capability and virtualization (Smit et al., 2016). CDM enables a set of organizations to iteratively design their collaboration by building a recursive model governing it. This guides the specification of digitalized contracts regulating the collaborations and generates processes for coordinating the collaborative activities. CDM supports the following five key decisions required for creating collaborations:

T1. *Decomposing* manufacturing goals into more specialized sub-goals more aligned with SME capabilities.
T2. *Matching* goals or sub-goals with available suppliers, thus proposing virtual teams.
T3. Deciding how suppliers *operationalize* manufacturing goals via processes.
T4. *Decomposing* suppliers' processes and inviting outsourcing partners.
T5. *Defining discretionary process steps,* where an operationalization decision about a process step is left till collaboration execution time, and the collaboration design model only contains the goal which should be fulfilled at that step.

2. Background

The theoretical underpinnings of method development include works on situated action (Suchman, 1987), the ideals of contract net protocol (Smith, 1980), recursive design and evolution of collaborative business processes (Carpenter et al., 2006); Mehandjiev et al., 2007; Mehandjiev et al., 2008). The recursive model of collaboration which both guides and records the results of the team design process is based on synthesizing the core elements of existing enterprise ontologies such as TOVE (Gruninger et al., 2000), REA (Geerts and McCarthy, 2002), Enterprise Ontology (Uschold et al., 2008), Ariadne (Schmidt and Simone, 1996), SAP Ariba[1]. It was also inspired by related research on collaboration (Mehandjiev et al., 2007; Lin and Ishida, 2014), consolidation of production capabilities into virtual teams (Grefen et al., 2010; Camarinha-Matos et al., 2017), works on adaptation of Industry 4.0 to SMEs (Müller et al., 2018). Unlike most of the coordination theories which only focus on activities, this work recognises the primary role of *goals* followed by collaborating companies. By guiding implantation of short-term business partnerships, production capabilities of several firms could be consolidated using collaboration rules

[1] www.ariba.com/ (accessed 16.09.2018)

and process composition— to form a larger entity and apply for larger business opportunities. Figure 1 describes the related flows of activities.

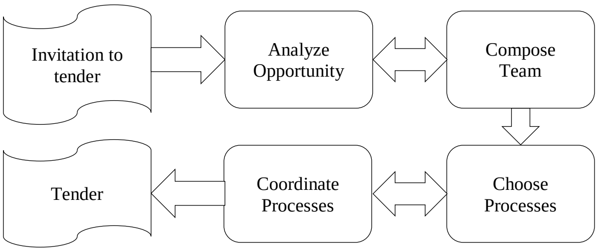

Figure 1. Flow of activities supported by the CDM.

Design science methodology advises cycles of relevance, design and verification to produce a purposeful artefact (Implementation of the Method) to address the issue of ephemeral inter-organizational collaborations (Hevner et al., 2007; Peffers et al., 2007; Wieringa, 2014). This work explains how a *purposeful artefact will address an important issue* of Industry 4.0 (set of principles) and the focus of this paper is underpinned by the following research question:

RQ *How to design B2B collaborations based on manufacturing goals and available suppliers' processes leveraging Industry 4.0 principles*?

3. Collaboration Design Context

In the context of the European Commission Horizon 2020 (EU H2020) programme promoting smart collaborative supply chain systems research, the first instantiation of the Method was made in SUDDEN[2], which focused on the creation of a collaborative team in the automotive sector. It included blackboard-based mechanisms for emergent team composition, process-aware evaluation of the set of proposed partners, and coordination mechanisms by bringing together ideas of collaborative planning and design of multi-tier supply networks, delayed partner recruitment and systematic evolution of supply chains. In contrast to our previous works (Table 1), the current project DIGICOR[3] shortens time for team formation even more (up to the real-time) using digital platform for digital coordination across conventional supply networks.

Table 1. Derived experience from the case studies.

Project name	Case studies	Main contributions
MaBE 2002-2005	Hanomag / Härtol / Peddinghaus Magna Intier BMW X series	Agent-based formation of virtual enterprises
Cross Work 2004-2006	Automotive Cluster in Upper Austria MAN waterpump	Methods of VE formation and the design of cross-organisational workflows
SUDDEN 2006-2009	Graf Carello electric vehicles	Recursive model of a virtual enterprise
	Schneegans Silicon - Oil dipstick	Approach to collaboration design and optimisation of supply networks by SMEs
ARUM 2012-2015	Airbus– disturbance management Iacobucci IHF/ MGS – Re-inspecting faulty components	Information system to manage disruptions during ramp-up deliveries
DIGICOR 2016-2019	Airbus – Group Innovations Hanse Aerospace – SME Cluster	Tools for tender decomposition and matchmaking
	C2K- SME Cluster	Agent-based formation of collaborations on demand

4. Aerospace industry context

A large-scale European aerospace OEM - relies on deliveries from Tier-1 suppliers but prefers to see more modules coming from smaller suppliers that bring new ideas and innovation. To avoid high costs of coordinating hundreds of these, OEM expects to receive tenders from virtual teams with a lead supplier responsible for the delivery. In order to understand, why such partnerships fail nowadays, the interviews with 17 CEOs representing a spectrum of

[2] cordis.europa.eu/project/rcn/79353_en.html (accessed 16 March 2018)
[3] www.digicor-project.eu/ (accessed 15 April 2019)

aviation and space-oriented service SMEs have been held (Kazantsev et al., 2018). They have shown that SMEs might potentially develop and supply sub-assemblies for aircrafts in virtual teams, but lack resources and access, knowledge and collaboration experience, suffer from distrust, opportunism fears among others (Table 2). They also lack clarity of how a potential team might be formed, interconnected and guided that was used as requirements whilst shaping the method. The excerpt of reported barriers is positioned against managerial activities of forming network structures (Moller and Hallinen, 2017).

Table 2. Collaboration barriers and requirements.

Managerial activities *(Moller and Halinen, 2017)*	**Barriers (excerpt)** *(Kazantsev et al., 2018)*	**Method steps to remove barriers**	**Industry 4.0 principle** *(Smit et al., 2016)*
Visual and sense -making	SMEs being unfit for a tender (e.g. size, volume)	(T1) *Decomposing* tender *goals* using product ontology, making thus chunks (G, I) referred later as tasks	Decentralisation Modularity
Mobilizing network actors and constellation creating Goal construction and organizing	Partner search costs Network distrust Partner opportunism	(T2) Assigning goals to suppliers	Real-Time Capability Service Orientation
Efficiency seeking	Costs of data interchange with customers	(T3) *Operationalization of goals keeping* alternatives (T4) *Decomposing resulting processes*	Virtualisation Inter-operability
Efficiency seeking	Coordination costs	(T5) *Defining discretionary process steps* resolving interdependencies between activities.	Service Orientation Real-Time Capability

5. Findings

5.1. Collaboration ontology

The Collaboration ontology allows construction of two recursive decomposition paths forming the model: a goal decomposed into sub-goals and a process decomposed into sub-processes. The two decomposition paths are interlinked with operationalisation choices and with discretionary step definition links, forming a model shared between all collaborating organisations which use the model to coordinate their activities. The core ontology is extended with elements of manufacturing ontologies and formalised in OWL to facilitate reusability, extensibility, robustness, conciseness and auto classification (Schmidt and Simone, 1996; Antoniou and Van Harmelen, 2004) (Fig.2).

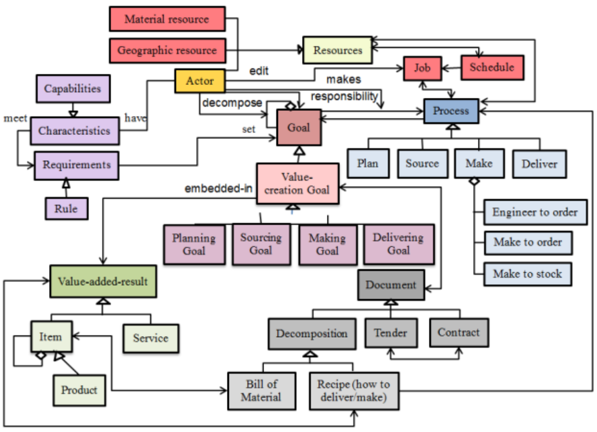

Figure 2. Collaboration ontology used for the method.

5.2. Steps to construct the collaboration model (the Method)

The following five key decisions define how the supplier collaboration may be organized at inter-organizational levels. The sections below describe the essence of CDM and define how the multilevel supplier collaboration may be organised between organisations.

1. *Decomposing Invitation to tenders to a hierarchy of goals*: An invitation to tender typically outlines the goods and services with clear quality, delivery, timing, volumes and other requirements. Each element of the invitation to tender comprises sub-elements that provide a natural, unambiguous decomposition, like a product that is composed of subassemblies, systems, parts, etc. This information is contained in a product structure breakdown (PSD) or bill of materials that (1) provide a natural means through which to decompose each good

or service identified in the invitation to tender and (2) allows to identify how the overall goal of fulfilling the requirements of the invitation to tender. For example, if we have a product to deliver, then we need to create the product and then deliver it; thus, we can identify a clear goal: *create_product*. Using the PSD, this overall goal of *create_product* can be re-written (recursively) as a series of subgoals. For example, suppose that our product comprises two systems, *system_A* and *system_B*, then we can re-write as follows: *create_product ← assemble_systems*, *create_system_A*, *create_system_B.* Each of these subgoals can be refined further by making use of the PSD at a more refined level. At each stage, the (sub) goals can be compared with the expertise and services provided by the partners in the cluster of companies working together and currently available for participation.

2. *Assigning responsibilities to suppliers*: An actor-centred view of coordination (Mehandjiev et al. 2003) is used for organizational structures analysis and business process management under static settings to consider changing environmental factors. Each (sub) goal is specified as a set of requirements, deriving from the goal decomposition and the requirements of the invitation to tender. The Collaboration ontology, outlined in Fig. 2, shows that these requirements are met by characteristics that belong to the actors (i.e., companies) in the network. Thus, at each level of decomposition of Step 1, the requirements of each (sub)goal can be compared with the characteristics of available actors (suppliers); if a given (sub)goal can be fulfilled by a supplier, including quality requirements, certification constraints, capacity, etc., then that supplier is assigned responsibility (or becomes a candidate if there are two or more "qualified" suppliers[4]) for that (sub)goal. Thus, the decomposition process of Step 1 and the assignment process of Step 2 continually interact.
3. *Operationalizing goals*: According to the level of abstraction, an actor may devise a decomposition of the goal into smaller goals, sub-goals; or if suitably specific, identify a process for the attainment of the goal, which we refer to as an operationalisation choice. Such choices are often impacted by several (external) influencing factors. The decomposition and operationalisation are two of the core change operators, which are used to implement iterative elaboration. Once a supplier is assigned responsibility for a goal, it will choose the process through which it intends the goal to be achieved. In many cases, the operationalization choice will be straightforward; however, in other cases, according to the complexity of the goal and the level of abstraction, it may be that the supplier needs to further decompose the goal in a manner analogous to step one and assign responsibility to resources under its own control or to appropriate subcontractors in a manner analogous to step 2. In the context of Industry 4.0, this step links with steps 4 and 5. A supplier might have the capability for certain processes in-house, but also outsource these according to available capacity. Moreover, such operationalization choices may change in a matter of hours. In such scenarios, we have that a decision to make something in-house becomes a decision to outsource owing to a dynamic change in in-house capacity, or vice versa. This is reflected in the change of operationalization from (say) a "make" process to a "source" and "deliver" process, or vice versa. This has an impact on both the operationalization and the structure of the goal. As we discuss further below.
4. *Decomposing processes*: A process may be simple, a single step; or composite, a partially ordered set of steps, i.e. subprocesses. Analogously to sub-goals, each sub-process may itself be simple or complex, thus, providing the second (operational) stream of recursive elaboration of our model. The elaboration of a process with a partially ordered set of sub-processes is thus the fourth operator in our approach. Based on the operationalization choices available for each goal owned by a supplier, we have a choice of processes that lead to a decomposition of processes as well. The most appropriate decomposition will depend on the available capacity of both the supplier and potential subcontractors. This becomes particularly interesting in the case of a supplier being able to partially fulfil a given goal in-house but needing to outsource part of the goal attainment. This will give rise to a partial order of processes: "make" for the in-house aspects and "source-deliver" for the outsourced aspects, which can be done in parallel (or have not necessary sequence), followed by the combination of these two processes to fulfil the goal.
5. *Defining discretionary process steps*: The choices made by actors in operationalising goals give rise to specific processes which are typically interdependent. Not all decisions about process steps can be made at the time of designing the collaboration, so certain process steps can be left without execution-level detail, only pointing to a goal which should be fulfilled within that process step. In effect the operationalisation choice for that process step is left till the time of executing the collaboration, avoiding premature commitment to a process which may prove unsuitable at run-time. An example of such a decision could be the logistics service, where parts can be shipped by air or by ship.

6. Example application

TurboCo is a recently started supplier by several entrepreneurs that specialises in modern design of lavatories in public transport. This time they recognise that OEM publishes an invitation to tender with only one goal of supply an innovative lavatory module for its new aircraft OEM980 (G0). TurboCo reacts to the invitation and starts

[4] Note, we do not deal with how we choose among candidates here.

assembling a collaboration of companies to tender for supplying the requested product). Since TurboCo has not enough capabilities for such procurement; it firstly decomposes G0 into sub-goals following a Bill of Materials (BOM) breakdown suggested by the invitation to tender: G1 to G4. This applies the first step T1 – *goal decomposition* and moves the state of the collaboration model along the goal decomposition dimension. TurboCo decides to assign G1.1 "Supply Sidewall" to itself by making the allocating responsibilities decision and expanding the model in that second dimension of actors getting *allocated responsibilities for goals*. TurboCo still does not have a complete know-how to supply the 'Sidewall' but they can undertake the sub-goal of "Plan Sidewall" (G1.1.1) whilst outsourcing the goal G1.1.2 "Make Sidewall" to ExecCo, another supplier, found because of the match between G.1.1.2 requirements and ExecCo Profile. Since ExecCo is responsible for G1.1.2 and they operationalise this goal. They select Process 2, thus developing the collaboration model through the third decision type (T3) of *operationalising goals through processes*. ExecCo allocates resources and steps details in Process 2, apart from the last step of Deliver 'Sidewall'. This extends the collaboration model through the fourth decision type (T4) of *process decomposition*. The reason for "Deliver Sidewall" step to be left out of the process elaboration and denoted as discretionary is that a decision as to how to implement the delivery is best left to the time of the actual delivery, to consider a number of contextual factors such as weather, demand scale, etc. MakeCo thus only tags the process step with the Goal G1.1.3 "Deliver Sidewall (delayed)", expanding the collaboration model through the final decision of *discretionary step definitions* (T5).

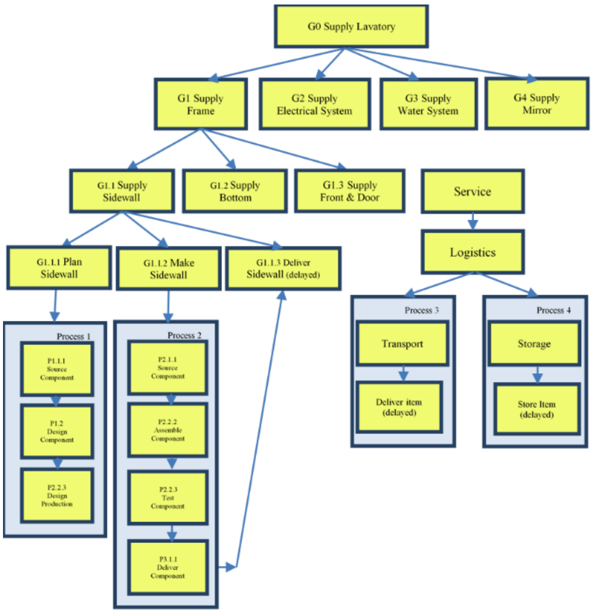

Figure 3. Decomposition of Goals and Competencies.

7. Evaluation of identified results

International supplier expo Aircraft Interiors is a world's leading event for suppliers that demonstrate their latest technologies and products for the cabin interiors and inflight entertainment. Such event in Hamburg, Germany 10-12 April 2018 has brought a feedback of suppliers to the current developments. The supplier cluster of an analysed OEM arranged a round table and attracted 9 suppliers for interviews that confirmed their suitability to the current requirements of aerospace manufacturing regarding flexibility and speed.

8. Conclusions

The application example shows how the proposed method can overcome the barriers for collaboration in a virtual team, for example: the problem of scope is addressed by breaking down the overall goal into smaller components of product ontology (items), which can be allocated to different suppliers; the quick matchmaking and the problems of reliability is realised by constructing a collaboration model which allows to execute-time reconfiguration of processes and even responsible partners. The current work is oriented towards adjusting specific governance rules and resolving interdependencies between supplier activities (step 5 of the method) that may share input/output resources.

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