Demand-driven Collaboration in the Aerospace Industry 4.0: Application of Subject-oriented Process Management

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Abstract. From the early 2000's Original Equipment Manufacturers (OEM's) pursue activities to reduce resources spent on collaboration with their component suppliers. For transfer of long-term strategies in their operational workflows companies use cross-organizational business process management. In this paper, we design top-level networks for demand-driven collaboration between aerospace OEM's and SME's. For this regard, we apply a Subject-oriented Process management methodology to draft interaction models between these actors. These results support Industry 4.0 research in the area of demand-driven collaboration, short-term partnerships and flexible work automation.

Keywords: S-BPM, Aerospace industry, Industry 4.0.

1 Introduction

Active participation of the entire workforce across the organizational hierarchy cf. *Kaizen* refers to enable collaboration activities that continuously improve all functions and involve all employees from the CEO to the assembly line workers. In accordance to this concept, Subject-oriented Business Process Management (S-BPM) [1], [7] gives for every employee five symbols to model any process that later transforms into executable form of inter-organisational setting. In this paper, we apply such vision for suppliers of large-scale manufacturers (OEM's) in the aerospace industry. We believe the application of S-BPM methodology to the described business case initiates supplier discussions, increases their engagement in process optimisation work and results in more acceptable process models. Moreover, this methodology allows business users quickly adjust their standard model depending on the new collaboration and their feedback from the previous one. This made us think that S-BPM is more suitable than other approaches with respect to formation and with respect to modelling processes for the current case. During series of workshops, we encouraged suppliers to come up with ideas – however small – that could improve his/her business activity in desirable value chains, job environment or any intra-organisational process for that matter.

2 Goals & Objectives

The main goal of this paper is to model cross-organisational demand-driven collaboration processes between aerospace manufacturer and their multi-tier suppliers to deliver the requested order. To achieve this aim, we analyse the aerospace industry where the large-scale manufacturer deals with supplier relationship uncertainty and coordination challenges and model processes using S-BPM notation in Metasonic. The paper is developed as follows: Section 3 overviews the main notions, the aerospace business case is described in Section 4, S-BPM models are presented in Section 5.

3 Key Concepts

Original Equipment Manufacturer (OEM) is a company that procures components from suppliers, assembles the branded product and sells it to end-customers. Suppliers to OEM constitute multi-tier networks, where the proximity to OEM increases the delivery importance and the amount of shared risk. However, maintaining networks of suppliers represents a certain difficulty, mainly due to direct collaboration costs that become a burden for manufacturers [12]. Moreover, some of suppliers are too small and should not have a direct supply relationship to OEM without creating a joint entity. Since OEM, much intends to reduce increased costs on collaboration, and asks its suppliers to share risks – that is yet hardly possible without ensuring accepted common goals, collaboration rules and established infrastructure for production process monitoring. Risk-Sharing Partners (RSP) – or trusted tier-1 suppliers - keep responsibility of the integrated product units and deliver it to the OEM for the final assembly. Such companies form a multitier production team, which could consist of available suppliers with surplus capacities from various supply chains. They may even include competitors [13, 14] protected by intellectual property and data protection policies.

Industry 4.0 provides infrastructure for creating a “digital twin” of the supply chain via progress monitoring of participating suppliers shop floors real-time. The potential form of supplier collaboration to support such context is demand-driven collaboration. It transforms “…conventional supplier -buyer relationships into collaborative partnerships within a network, facilitating joint product design and deployment of integrated logistics” [2]. In this regard, suppliers can exploit existing business opportunities in various industries, utilise their excess capacities, thus increasing product availability and reduce costs ([3], [4], [5]). Such collaboration must not lead to creation of a new legal entity; instead, the participating companies are forming virtual enterprises [3].

This concept of virtual enterprises as joint efforts responding to business opportunities has been around for a while. However, the recent technological shifts created a shift in its development. For instance, potential complete automation of the supply management via of cyber-physical systems, advances in communication technologies between various autonomous and geographically separated enterprises - now allows creation of virtual enterprises instantly, to react on the appeared business opportunity immediately [3], [12]. Additionally, cyber-physical systems facilitate production of by decentralisation of governance and automated quality control [6]. The Industry 4.0 provides these

opportunities to formalise demand-driven collaboration via instantly created and short-term existing business entities instantly virtual enterprises [3].

4 Business Case

For our case we have selected a Multinational Aerospace Corporation (we refer to it as an OEM), that relies more and more on suppliers for delivering innovations. That is why the corporation implements several initiatives to better utilise the innovation potential of related SME's, especially considering management of delivery ramp-up in time and establishment of new aircraft programmes. The second participant is an Association of Aerospace SME's (AAS), representing a wide spectrum of suppliers and maintenance companies to aviation and space oriented service companies and mainly supplying OEM. The Association plans to expand its portfolio worldwide, to manage changes in supply chains and to collaborate with new partners for complex products and services in an easy way. Both OEM and AAS are interested in the emerging Industry 4.0 concept and keen to explore its benefits, opportunities and current barriers that impede is application.

In general, OEM and AAS pursue two kinds of cooperation:

- "virtual" Cooperation: ad-hoc demand-driven collaborations in form of virtual enterprise
- "non-virtual" Cooperation: collaboration in an established legal entity

The application of S-BPM methodology results in more acceptable process models and allows business users quickly adjust their standard model depending on the new collaboration. During modelling, we concentrate on a virtual Cooperation because it characterises the short-term collaborative nature of Industry 4.0 production networks, that corresponds to works [8], [9], [10] and [11]. In such settings, every supplier may create a virtual consortium for fulfilling the requested task. After collaboration, the network dissipates, and all partners continue working with their traditional markets. One company has to take over the leadership for the consortium and act as the point of contact for customers and suppliers of the consortium during the project.

A non-virtual cooperation can be a result of a virtual cooperation, when partners build a real institution or legal company for a longer time. All partners hold shares in this entity and it can act autonomously from the shareholders.

5 Results

If OEM starts a call for tender for a new aircraft, normally the tier-1 supplier (Risk-Sharing Partner) gets an order. Potentially, not having enough production capacity (or missing some tender capabilities), the tier-1 supplier is searching for tier-2 suppliers which potentially may develop the required system components. Aspects for collaboration between tier-1 and multi-tier suppliers intersect with the aspects of trust, information privacy and risk acceptance in business activities, common interfaces and data

transformation. To model communication within the production process we generalize the high-level process model to the extent that each supplier's own structure matches it.

Due to the complexity of the process, the entire model divides into three layers of abstraction: strategic, tactical and operational:

1. The high-level collaboration within all supply chain members:
   a. The Subject Interaction Model of actors:
      (1) Customer
      (2) OEM
      (3) Suppliers through Collaboration Node
   b. The Internal Behaviour Models of:
      (1) OEM
      (2) Collaboration Node (automated)
      (3) Virtual Supplier
2. The process of supplier's selection;
   a. The Subject Interaction model of Virtual supplier
   b. The internal behaviour of:
      (1) Group of analysts
      (2) Engineering Group
      (3) Internal System subject (automated)
      (4) Collaboration Node (automated)
3. Demand-driven virtual supplier formation
   a. The subject interaction model of forming a virtual supplier
   b. The internal behaviour of the Collaboration Node subject (Information System)

For these process models we define goals, boundaries and expected results, all subjects (actors), formalise the messages that subjects send/receive and specialise subject's behaviour.

5.1 The High-Level Collaboration Model

In the current business case the value chain incorporates virtual enterprises that allow flexible decoupling of suppliers and small to medium enterprises (SME's) to assemble the aircraft for the Customer. These participating actors (i.e. subjects) are:

The Customer – any Airline

4. **Original Equipment Manufacturer** (OEM) – an aircraft manufacturer that assembles all delivered components and customises aircraft under its own brand
5. **Collaboration Node** (COLN) – a data collection and processing system, which registers suppliers, facilitates and traces actions during collaboration of multi-tier suppliers.
6. **All Suppliers** (multi-subject) – all suppliers who can participate in the OEM tender
7. **Virtual Supplier (**multi-subject) – created virtual enterprise for a particular tender

The next step is to identify messages between subjects, **Fehler! Verweisquelle konnte nicht gefunden werden.**.

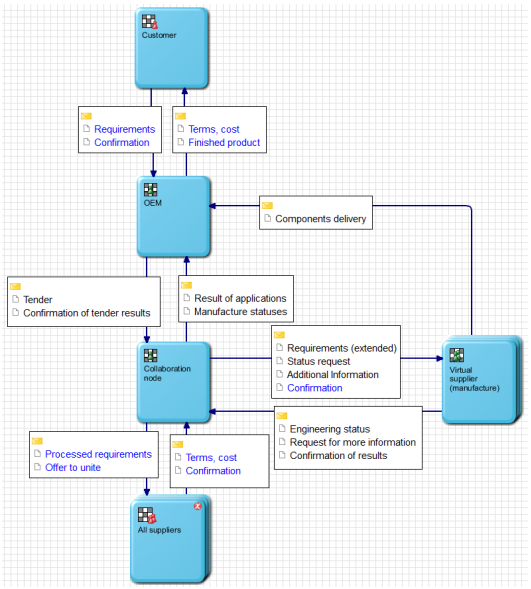

Fig. 1. The Subject Interaction Model

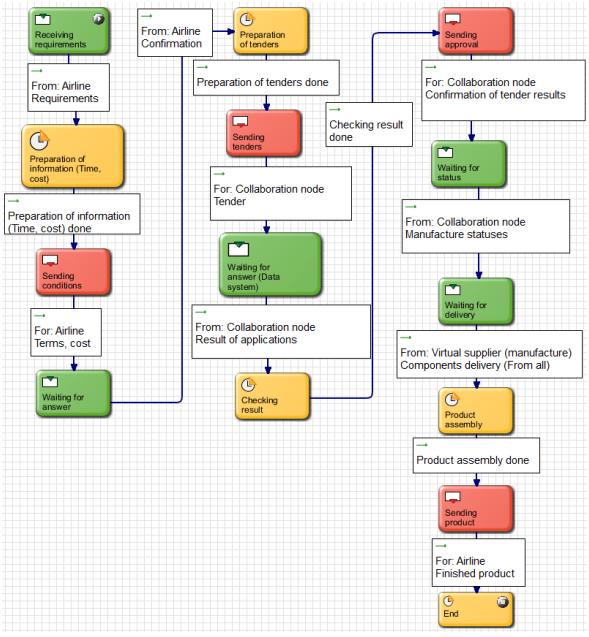

Fig. 2. The Internal behavior of OEM

On the Subject Interaction Model (Fig. 1) OEM and the Airline (Customer) exchange and confirm tender requirements. OEM uploads this in the document form to COLN, thus decomposing this tender into smaller business opportunities visible for all suppliers, ranging potential suppliers based on their capabilities and earlier references, sending invitations to take part in the tender and providing the procedure to create a Virtual Supplier.

The Collaboration Node tracks the production: collects production delivery statuses, coordinates the actions of suppliers and summarises results in real-time reports. This subject also checks compliance between supplier's deliverables and customer requirements, which differ for each project / part of the project, absorbing data from supplier's cyber-physical systems (or conventional information systems).

Finally, the Virtual Supplier transfers the delivered components to OEM, that assembles them into the aircraft (existing procedure differences between Supplier-Furnished (SFE) and Customer-Furnished Equipment (CFE) are skipped in this model), and further delivers the aircraft to the Customer Airline. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows OEM subject behaviour. OEM confirms bidding results, and consolidates the product delivery with the Customer.

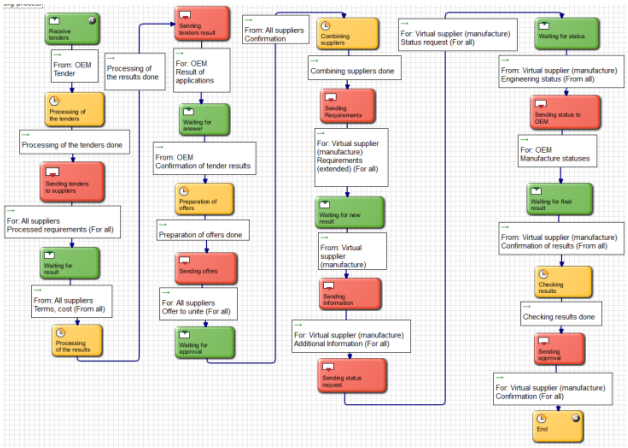

Fig. 3. Internal behavior of Collaboration Node

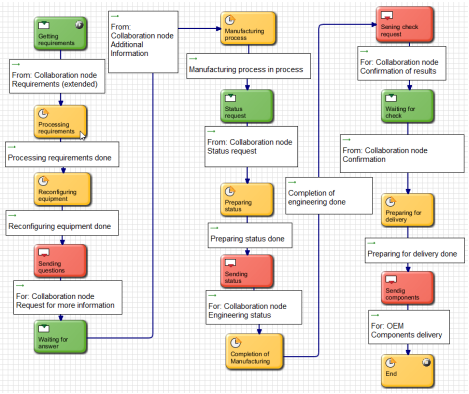

Fig. 4. Internal behavior of the Virtual supplier

5.2 The process of selecting suppliers for the virtual enterprise

In the current business case, the Risk-Sharing Partner applies for the tender from OEM, initiate demand-driven partnership and holds legal risks. The participating subjects in this process are:

1. **The Group of Analysts** (referring to OEM) – a sub-group of analysts who collect requirements and prepare documentation for the tender, as well as consult the suppliers, if necessary;
2. **The Engineering Group** (referring to OEM) – a sub-group inside OEM who designs a model for tenders with suppliers;
3. **The Internal System** (referring to OEM) **–** a corporate IS [internal system] used for data consolidation;
4. **Collaboration Node (COLN)** – a data collection and processing system in which registers suppliers and OEM's facilitate all activities;
5. **All suppliers** (multi-subject) – all suppliers can participate in the tender. This entity aggregates all available suppliers;

Figure 5 show messages exchanged between suppliers.

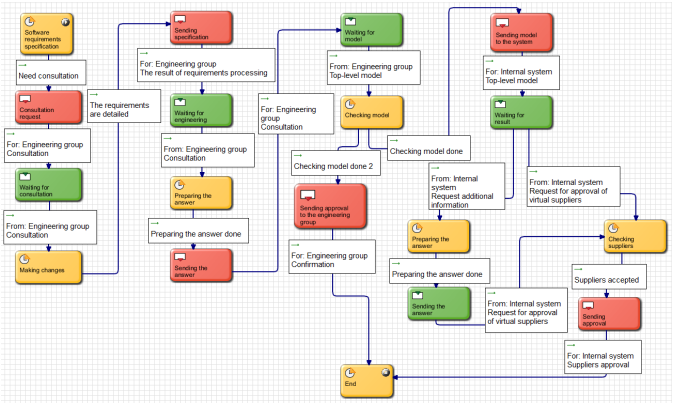

Fig. 5. The internal scenario of the Group of analysts

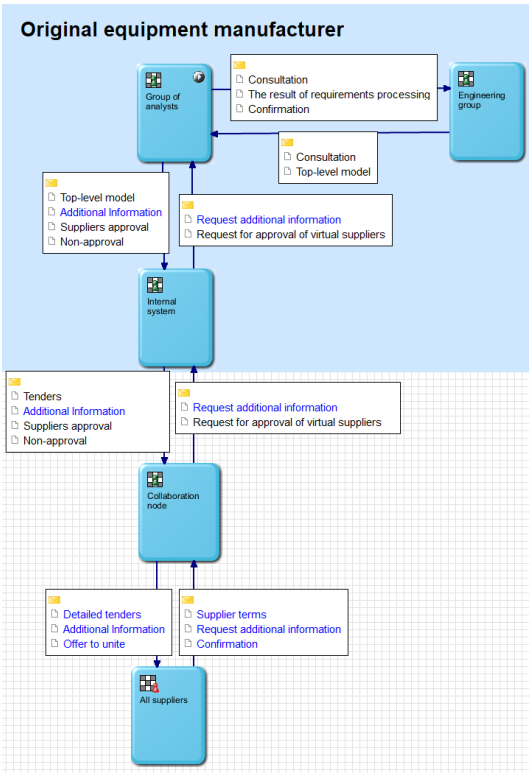

Fig. 6. The Subject Interaction model of Virtual supplier selection

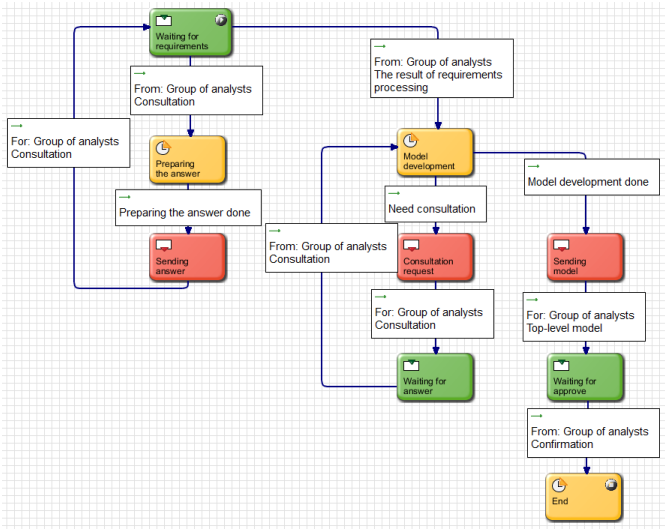

Fig. 7. The internal scenario of the Engineering group

The **Group of analysts** prepares requirements and passes them for consolidation to the **Engineering group**. The Engineering group prepares top-level models to launch the tender, selects suppliers and performs preparatory work for tender execution by suppliers. Further, suppliers exchange messages through the Collaboration Node with each other and with OEM, that can receive them either directly or through their own Internal IS.

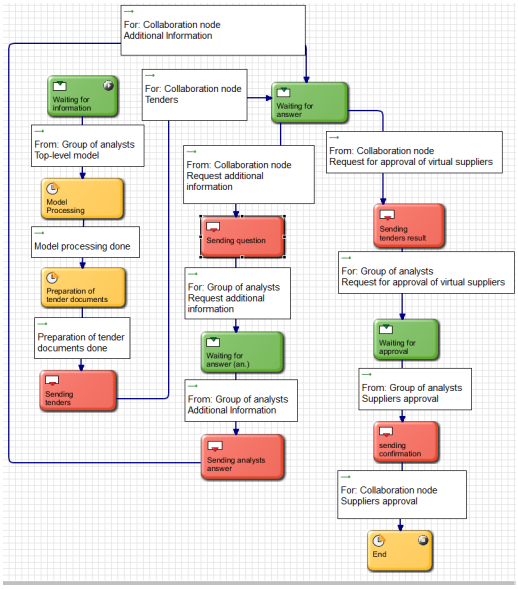

Fig. 8. The internal scenario of the Internal System subject

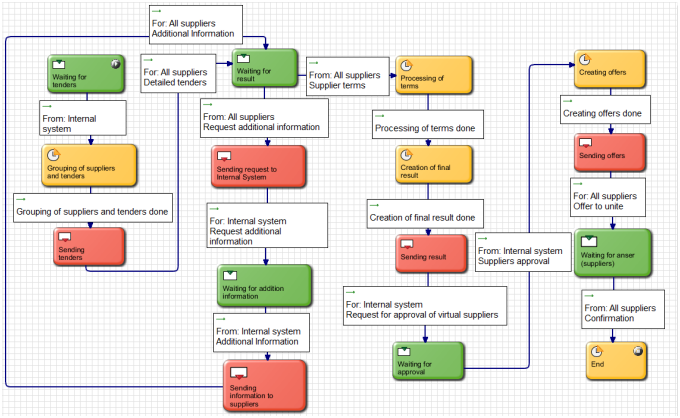

Fig. 9. The internal scenario of the Collaboration Node subject

The Collaboration Node organizes tender information, classifies suppliers according to the announced tenders, sends tenders to relevant suppliers and processes results with terms received from potential suppliers. Based on the analysis results, OEM gets recommendations for a virtual enterprise that later edit/confirm the group of analysts and participating suppliers.

5.3 Demand-driven collaboration following customer order

The last model describes the interaction of supplier's cyber-physical systems in the virtual enterprise for coordination purposes. The main goals of this model are adjustment of production plans, supplier's combination into the holistic production chain and supplier's equipment integration. The subjects are:

1. **Collaboration Node** –The main role of this system here is to prepare a final project, to ensure updates reach all suppliers and to transfer all requirements to the supplier's cyber-physical systems.
2. **Supplier's System** – The internal cyber-physical system of the supplier, which consolidates the shop floor activities. It facilitates final project plan tracking, and transfers claims to the factory systems.
3. **Factory's System** – The Factory's system is a multisubject of many factories within a supplier. The Factory's system provides production line data, free capacity and equipment reconfiguration periods. It follows the production plan and prepares settings for reconfiguring all equipment to project requirements (specifications).
4. **Conveyors** –a multisubject integration has many conveyors or other production facilities for the project implementation. The pipeline below visually reflects a message process being sent, which communicates settings for personalized order execution.

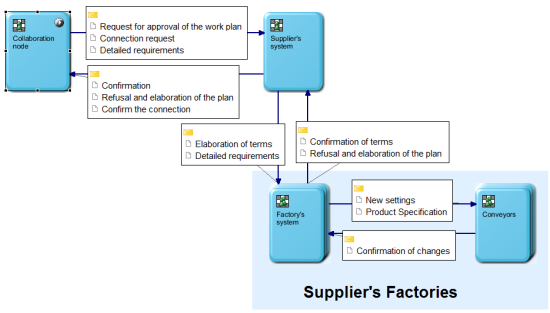

Fig. 10. The interaction model of forming a virtual supplier

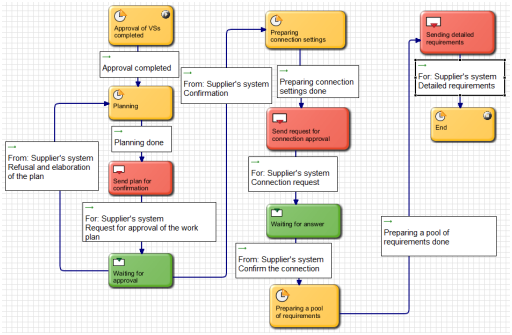

Fig. 11. The internal behavior of the Collaboration Node subject

Figure 10 represents the messages that the subjects exchange, where the main communication takes place during transferring plans for reconciliation, transmitting settings to collaborate in the virtual enterprise or transmitting detailed requirements for system components implementation. Based on detailed requirements, the subject transfers new settings to production facilities. Figure 11 shows internal behavior of Collaboration Node subject.

The Collaboration Node describes the negotiation of the plan, connects providers to form a virtual supplier and sends the new structure to detailed requirements. Further, the Suppliers' information system processes the plan and refines it with the factory system and then passes either an agreed plan or refinements for implementation. Time lag is necessary for virtual enterprise formation settings activation and for order requirements sharing between the relevant plants. The Factory's system confirms the timings and identifies vacant production lines in cases of equipment occupancy. It analyses order requirements and prepares the tuning for the conveyor's equipment to comply with customised order requirements. The Conveyors receive these requirements, set up their equipment and follow product specification for the developed product. In some cases, the semi-part additionally controls its quality by checking the integrated production plan with the real actions that were carried out on this semi-part during the whole value chain.

6 Conclusions

In this paper we demonstrate the application of Subject-oriented Business Process Modelling demand-driven collaboration of OEM, suppliers and cyber-physical systems in a virtual enterprise. The series of interaction with manufacturers and suppliers resulted in the set of S-BPM models. For other Industry 4.0 collaboration cases they have to be customised.

This paper delivers models at three layers of abstractions:

- Strategy: High-level interaction within the entire production chain
- Tactics: The process of selecting suppliers
- Operational: Formation of a customer order-driven by a virtual supplier

During these performed actions we explain the interaction between actors to implement the subject-oriented model. The results of this study facilitate negotiation of collaboration rules between aerospace suppliers, assist OEM's for developing collaboration strategies, and shorten resources spent on direct supplier collaboration.

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