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BUSINESS INTEROPERABILITY: DYADIC SUPPLY CHAIN PROCESS DECOMPOSITION USING AXIOMATIC DESIGN

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ABSTRACT

In today's competitive environment, companies must strive to cooperate in order to survive. Supply chain cooperation has become a strong asset relying on large integration and coordination of its well-structured processes. However, supply chain operations are conditioned by interoperability, for which until now is missing a tool that helps managers to identify and solve its problems. This article presents the supply chain process redesign supported by the Axiomatic Design Theory.

Keywords: business interoperability, axiomatic design, supply chain management, process interoperability.

1 INTRODUCTION

The fierce competition between companies requires networked cooperation such as supply chains (SC), in order to face the current market situation. In this context, business interoperability is an enabler that makes it possible to execute SC operations such as planning, sourcing, delivering, producing and returning, in a seamless fashion, permitting a suitable process alignment and information flow and guaranteeing high performance and competitiveness [Huhns *et al.*, 2002]. However, the lack of interoperability is an emerging issue in information technology (IT) based cooperation.

In this work we present a method to decompose the processes between two supply chain actors. The paper is structured as follows: section two makes a brief review on the key topics (business interoperability and supply chain operations); section three describes the methodology for analysing and re-designing the supply chain dyadic cooperation; section four presents an example of the process decomposition between two SC actors supported by Axiomatic Design Theory (AD); and, section five presents the conclusions.

2 BUSINESS INTEROPERABILITY

2.1 BUSINESS INTEROPERABILITY DECOMPOSITION

Legner & Wende [2006] defined business interoperability as "an organizational and operational ability of an enterprise to cooperate with its business partners and to efficiently establish, conduct and develop IT-supported business with the objective to create value". Since the original concept introduced by IEEE [1990], interoperability has grown into a wider subject, integrating several organizational, operational and technological areas, currently becoming a complex subject [Rezaei *et al.*, 2013]. IDEAS [IDEAS, 2003], INTEROP Framework [Chen *et al.*, 2008; Chen, 2006], ATHENA Interoperability Framework (AIF) [ATHENA, 2007], ATHENA Business Interoperability Framework (BIF) [ATHENA, 2007] and European Interoperability Framework (EIF) [IDABC, 2010; Vernadat, 2010] are examples of frameworks and researches that present different perspectives, which reflect the issues that one must tackle to achieve higher levels of interoperability, that is, to get close to the concept of "optimal interoperability" [Legner & Lebreton, 2007]. Accordingly, and based on the definition of Legner & Wende [2006], we propose the Business Interoperability Components as depicted in Figure 1.

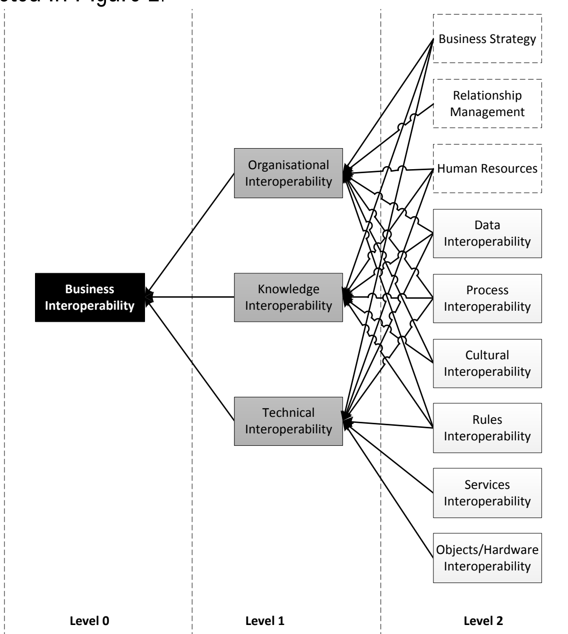

Figure 1. Business Interoperability Components.

These components portray individual perspectives of interoperability that, in each way, contribute to the concept of

Business Interoperability. This approach to the decomposition of business interoperability aims at systematizing the design of dyadic relationships using AD. This approach allows looking at the interoperability components to see how they guarantee an interoperable dyadic relationship.

2.2 PROCESS MODELLING AND THE SUPPLY CHAIN OPERATIONS

Modelling supply chain processes stems in the concept of process integration and coordination [Vernadat, 1996]. The supply chain operations reference model (SCOR), as introduced by [Supply Chain Council, 2010], provides a cross-industry standard in the definition and configuration of supply chain management processes. However, the SCOR model does not show how to proceed to achieve interoperability.

According to Chen [2006], process interoperability (PI) refers to the way internal processes from different companies interact with each other. The identification [ATHENA, 2005], sequencing [Chen, 2006; Chen *et al.*, 2008] and alignment [ATHENA, 2007; Tolk, 2003] of these processes are critical issues when designing the SC operations between two or more firms. Those authors stress the relevance of coordinating the internal processes into an interface or public process.

3 THE METHODOLOGY TO ANALYSE AND RE-DESIGN DYADIC COOPERATION

Figure 2 presents the method that is proposed to deal with the analysis and re-design of supply chain dyads.

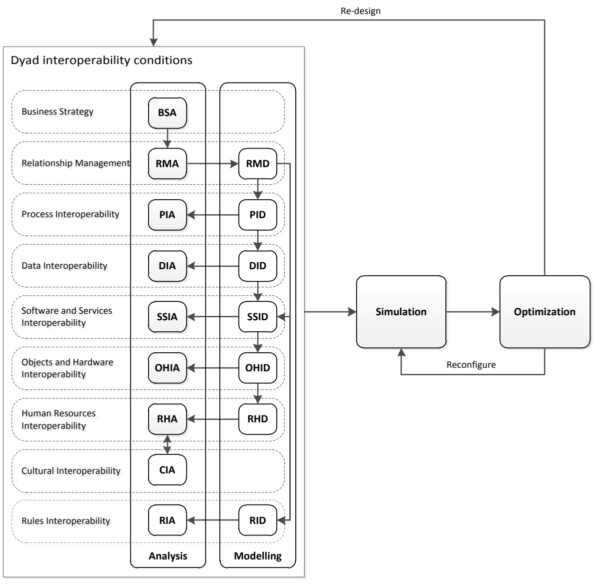

Figure 2. Methodology to analyse and re-design dyadic cooperation.

In this method, the first step is to analyse and model the dyad interoperability conditions in terms of the business interoperability components that represent the "as-is" situation. Next, one simulates the "as-is" model and one identifies the various scenarios that may lead to a more interoperable situation. At last, in the optimization stage, one finds which one of those scenarios has the best performance in terms of interoperability and in terms of supply chain performance.

3.1 STAGES OF ANALYSIS AND DECOMPOSITION

As mentioned in the previous section, the first step of the method is to determine the dyad interoperability conditions. This is achieved by interleaving the interoperability and the performance analyses, and modelling the interoperability components in a process that we call analysis and decomposition stages (A+D stages) (see Figure 2). The sequence of these stages has to do with the relationship between the business interoperability components. On the top of the method are the managerial and governance aspects, such as the business strategy and the management of the relationships that impact subsequent components. For instance, in business strategy analysis (BSA), the cooperation objectives are addressed and the dyad is analysed to verify if these ones are clear-cut to both companies and if the individual aspects are aligned into a cooperation business strategy. Managerial and governance aspects have impact in operations. Process interoperability decomposition (PID) and process interoperability analysis (PIA) are ruled by the prior aspects of interoperability, thus constituting the focus of this method. All the following stages are associated to the operations taken place in the dyad. For instance, data interoperability decomposition (DID) and data interoperability analysis (DIA) concerns to exchange of data between the firms that perform the processes. Issues like semantic alignment, communication paths and data quality are addressed in this stage in order to ensure that the data is properly interpreted, that there are sufficient contact points to exchange data, and that data is usable.

In terms of interoperability, the process resources are the information technology assets (software and systems interoperability, as well as objects and hardware interoperability) and the human resources. These resources enable processes and data exchange. As in the case of data interoperability, these resources are connected to the process interoperability.

3.2 PROCESS INTEROPERABILITY DECOMPOSITION (PID) AND ANALYSIS (PIA)

As stated before, process interoperability is the core of the method. Governance and management impact interoperability and two main elements rule the interaction between enablers and resources: the modelling and the analysis of the processes. The first element is the so-called process interoperability decomposition (PID), where individual and interface process identification, sequencing, and monitoring are addressed by using Design Structure Matrix (DSM) [Eppinger & Browning, 2012], Business Process Modelling Notation (BPMN) [Fettke, 2008] and supply chain practices implementation, in order to find which are the aspects that drive cooperation towards better effectiveness and efficiency. Figure 3 describes the method for decomposing a process in a dyad. For each actor in the SC dyad, we propose the characterization of each process (PI_1), the sequencing (PI_2) and the identification of the monitoring resources (PI_3). Next, the processes are aligned with the organisational structure of the company (PI_6). At last, after representing the company's internal processes, the interface process is created by aligning individual processes into a collaborative process (PI_5).

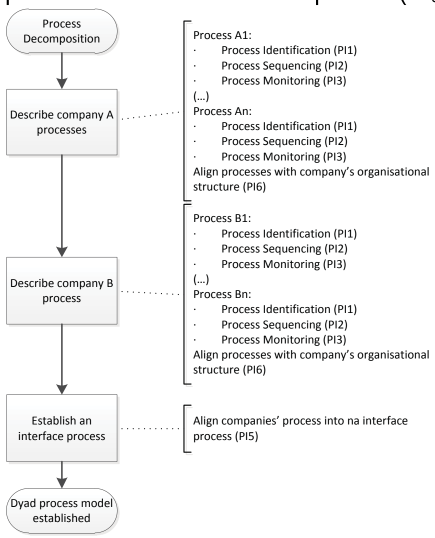

Figure 3. Process interoperability decomposition (PID) **method.**

Process interoperability analysis (PIA) is done after decomposing the process, and we suggest assessing the alignment and the visibility, as well as the appropriateness of the organisational structures to the processes. Both the process and the organisational alignment are addressed in qualitative and modelling standpoints. On the one hand, one makes a qualitative evaluation of the actors of the dyad; on the other hand, one verifies these two factors for better workflow arrangement and distribution through the companies' sections by using the DSM approach with optimization algorithms.

4 EXAMPLE: AUTOMOTIVE SUPPLY CHAIN DYAD

As an example, a 2nd tier raw material supplier (company A) and a 1st tier supplier (company B) constitute the dyad under analysis. On the AD perspective, the costumer in this case is the dyad. Hence, the top-level costumer need (CN) is to ensure high level of interoperability that should be achieved by the design of the sourcing and the delivery operations.

The interoperability conditions in terms of business strategy and process interoperability are specified in the design of Table 1.

Table **1.** The dyad business strategy and process interoperability conditions.

FR_0: Ensure interoperability on sourcing and delivery **operations**.	**DP_0: Systematic design of the dyad.**
FR_1: Establish the cooperation goals and conditions for the dyad.	**DP_1**: The negotiation of a contract.
$FR_{1.1}$: Establish purchasing requirements.	$DP_{1.1}$: The company B's purchasing model.
$FR_{1.1.1}$: Settle an agreement for lead-time.	$DP_{1.1.1}$: The standard lead-time is one week.
$FR_{1.1.2}$: Define the deadline to reject orders.	$DP_{1.1.2}$: The supplier (company A) has five days to reject an order.
$FR_{1.1.3}$: Establish the payment conditions.	$DP_{1.1.3}$: The payment is authorized only after receiving the invoice and the materials.
FR_2: Manage internal and interface processes of the cooperation.	**DP_2**: The role assignment, the process design and the coordination of the sourcing and delivery activities.
$FR_{2.1}$: Define the company B processes.	$DP_{2.1}$: Company B is the buyer and performs the purchasing and reception operations.
$FR_{2.1.1}$: Define the purchasing process.	$DP_{2.1.1}$: The features of the purchasing process.
$FR_{2.1.1.1}$: Define the inventory policy.	$DP_{2.1.1.1}$: The inventory level is defined every week by the materials resource plan (MRP).
$FR_{2.1.1.2}$: Define the procedure to place an order.	$DP_{2.1.1.2}$: The purchasing is performed by sending the order schedule and waiting for order fulfilment.
$FR_{2.1.1.3}$: Define the order validation method.	$DP_{2.1.1.3}$: The orders are considered accepted except in case of delays and rejection.
$FR_{2.1.2}$: Define the payment procedure.	$DP_{2.1.2}$: The payment is made after receiving the invoice and the products physically.
$FR_{2.1.3}$: Sequence company B's individual tasks.	$DP_{2.1.3}$: The design of the process, material and information flows on purchasing process (see "Figure 4.").
$FR_{2.2}$: Define the company A processes.	$DP_{2.2}$: Company A is the supplier and is responsible for receiving orders and deliver materials to company B according to the pre-established lead-time.
$FR_{2.2.1}$: Define order reception procedure.	$DP_{2.2.1}$: Company A receives an order schedule and checks the inventory level to fulfil orders.
$FR_{2.2.2}$: Define the order validation procedure.	$DP_{2.2.2}$: Order validation performed by checking stored materials and production availability.
$FR_{2.2.3}$: Sequence company A's individual tasks.	$DP_{2.2.3}$: The design of the process, material and information flows on delivery process (see "Figure 5.").
$FR_{2.3}$: Align companies' internal processes.	$DP_{2.3}$: Interface process.

The corresponding design matrix is depicted in Table 2. The dependency between FRs and DPs, which comes from the chosen DPs, conditions the design of the processes. For instance, the establishment of a deadline to cancel orders ($DP_{1.1.1}$) has direct influence in the definition of the method to validate orders on the purchasing process ($FR_{2.1.1.3}$).

PID method is applied to FR_2. Process identification (PI_1) is portrayed by $FR_{2.1}$, $FR_{2.1.1}$, $FR_{2.12}$, $FR_{2.2}$, $FR_{2.2.1}$ and $FR_{2.2.2}$. Process sequencing (PI_2) is applied to $FR_{2.1.3}$ and $FR_{2.2.3}$. Finally, the companies' internal processes alignment (PI_5) is applied to $FR_{2.3}$.

Table 2. Design matrix for the supply chain dyad.

	DP1	DP2	DP1.1	DP2.1	DP2.2	DP2.3	DP1.1.1	DP1.1.2	DP1.1.3	DP2.1.1	DP2.1.2	DP2.1.3	DP2.2.1	DP2.2.2	DP2.2.3	DP2.1.1.1	DP2.1.1.2	DP2.1.1.3
FR1	X																	
FR2	X	X																
FR1.1			X															
FR2.1			X	X														
FR2.2					X													
FR2.3				X	X	X												
FR1.1.1							X											
FR1.1.2							X	X										
FR1.1.3							X		X									
FR2.1.1							X			X								
FR2.1.2							X				X							
FR2.1.3										X	X	X						
FR2.2.1													X					
FR2.2.2														X				
FR2.2.3													X	X	X			
FR2.1.1.1																X		
FR2.1.1.2																X	X	
FR2.1.1.3								X										X

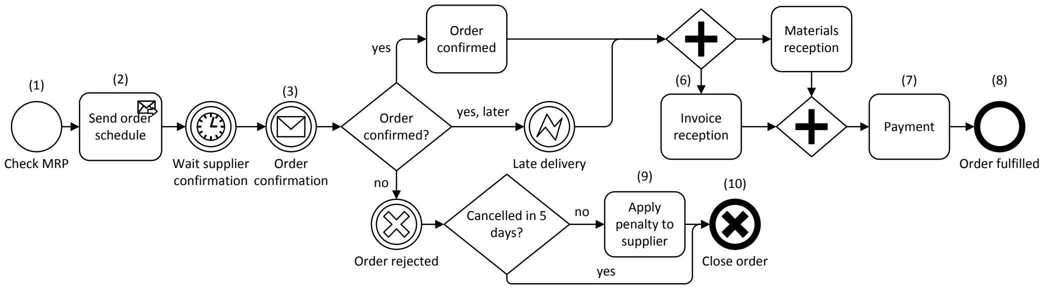

Figure 4. Company B's purchasing business process model (**$DP_{2.1.3}$**).

As for FR_2, stating the main operations and the procedures that must be used to achieve the sourcing and delivery goals specifies the process considerations. $FR_{2.1.3}$ corresponds to the alignment of the tasks of company B with the business process flow. The existing conditions of company B are presented in Figure 4. The process sequence is a direct consequence of the FR and DP decomposition. For instance, purchasing condition $DP_{1.1.3}$, establishes that the payment activity is preceded by a set of parallel activities: invoicing and reception of materials, which are requirements for making payments. Delays in any one of those activities will delay the payment to company A. Also, the condition $DP_{1.1.2}$ results in an additional process (see (9) in "Figure 4.") that, in case of order rejection delay, will result in negotiation of penalties.

In turn, the process of company A is presented in Figure 5, which portrays the sequence of the business procedures that should be performed to receive ($FR_{2.2.1}$) and validate orders ($FR_{2.2.2}$).

The next step in the proposed method is to align these processes with the company's organisational structure. In this example we are dealing only with one company section. Hence, the next step is to design the interface processes. Here, data, material and currency flows are mapped to interconnect the business processes. The result for the existing conditions is presented in Figure 6.

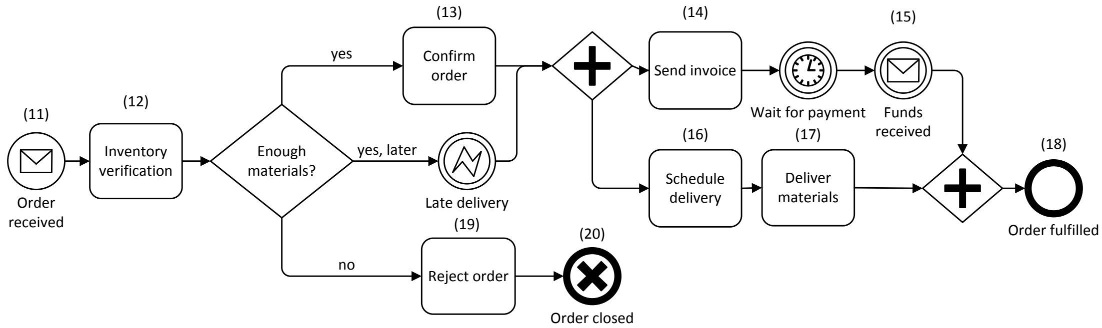

Figure 5. Company A's business process model (**$DP_{2.2.3}$**).

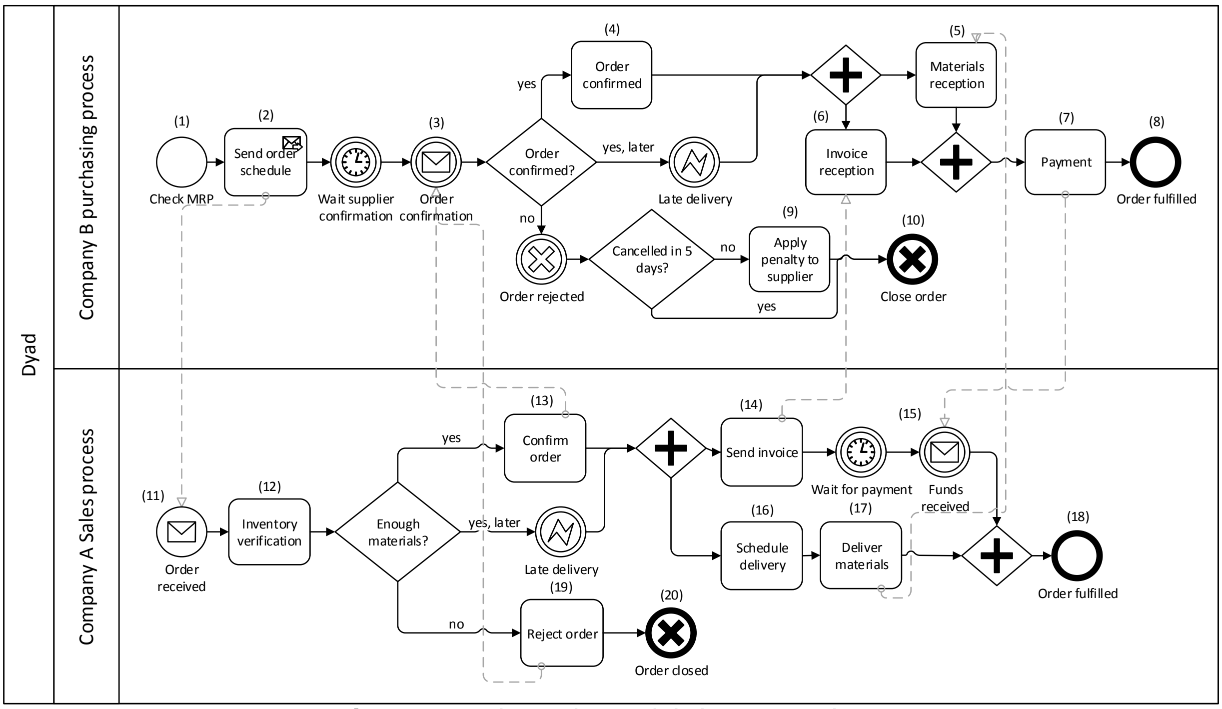

Figure 6. Dyad sourcing and delivery operations.

Representing the internal and the interface activities in a DSM (see Figure 7) allows visualizing the interactions between processes. The numbered activities of Figure 7 correspond to the numbers shown in Figure 6.

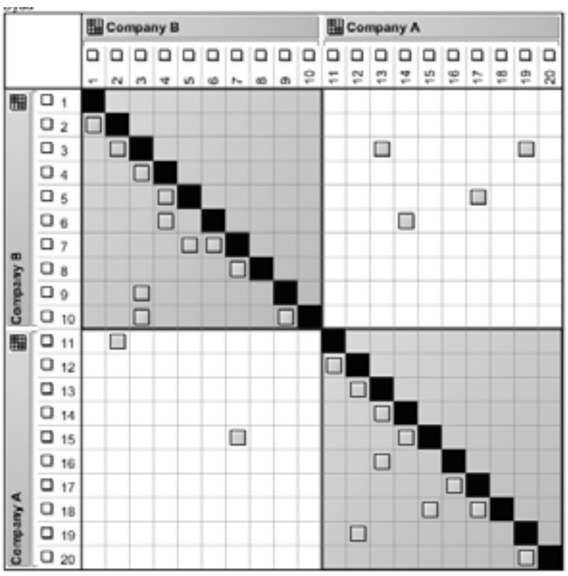

Figure 7. A DSM representation of the dyad (DSM made using the software "Cambridge Advanced Modeller" developed by **Wynn** ***et al.*** **[2010]**).

One should notice that there are six interactions in the interface of the two companies. We must act on those ones in order to identify and solve the interoperability problem. For example, both BPMN and DSM representations show a strong dependency between the purchasing and the sales processes. Checking the MRP and placing an order initiate the purchasing process. After placing the order, the procedure stops until company B confirms or rejects it. In the perspective of company B, the order placement is what triggers the sales process. The process is almost fully executed and, if the order is confirmed, it stops again waiting for the payment of company A. However, company A only makes the payment when the invoice and the materials are received. The activities in both companies depend on each other in the interactions (14)-(6), (17)-(5) and (7)-(15) (see Figure 7). This complex operation deserves great attention in modelling and in applying the subsequent A+D stages. The effectiveness of the process depends on the features of each one of the interactions and on the available resources. The effectiveness is studied through simulation as a means to check if the procedures generate delays on each other. The result of this study may require the re-configuration of the dyad in terms of information systems that enable the interactions (2)-(11), (13)-(3), (19)-(3), (14)-(6) and (7)-(15); or the material flow on (17)-(5).

5 CONCLUSION

The present research contributes to developing an integrated tool to assess and re-design IT-supported cooperation, using a systematic approach to identify interoperability problems, as well as to select optimisation tools to eliminate or to mitigate them.

The method presented in section 3 allows guiding the axiomatic design application by interleaving the analysis and the decomposition stages, while keeping the integrity of the business interoperability issues that are related to the industry sector under analysis.

The proposed method for process decomposition allows linking the governance and managerial issues to the operational reality of business. This is useful in dyad analysis and design because it allows keeping track of previously defined aspects when advancing the design. The presented example demonstrates that the cooperation objectives are very relevant in the process design, such as in the case of order cancelling deadline that influences the order validation process in both companies.

The Business Process Model Notation (BPMN) and the Design Structure Matrix (DSM) have particular relevance in modelling processes. BPMN allows easy forms of representing process, material, information, and currency flows and provides suitable symbols to represent information technology assets, users, communication, etc. As for the DSM approach, it allows to go deeper in the interaction between processes. As illustrated by Figure 7, the interactions that occur in the interface between the two companies become evident and it is possible to check where a process begins and ends. On more complex processes (*e.g.*, representing all the supply chain operations, such as production, planning, sourcing, delivery and returning) it is possible to allocate processes to organisational sectors (as proposed in section 3.2), and to verify the process alignment and distribution through clustering algorithms.

Future work will concentrate on applying the next stages of the proposed methodology. For example, after defining the process interfaces, data exchange will be modelled and analysed in order to identify information barriers, such as semantics faults, or database heterogeneity. At last, using simulation tools it will be possible to study various scenarios without interfering with the actual system, thus providing the solution that results in less cost and time.

6 REFERENCES

[1] ATHENA. (2005). DA1.4.1 Framework for the Establishment and Management Methodology (p. 62).

[2] ATHENA. (2007). DA8.2 Guidelines and Best Practices for Applying the ATHENA Interoperability Framework to Support SME Participation in Digital Ecosystems.

[3] Chen, D. (2006). Enterprise Interoperability Framework. EMOI-INTEROP. Retrieved from http://ftp.informatik.rwth-aachen.de/Publications/CEUR-WS/Vol-200/19.pdf

[4] Chen, D., Doumeingts, G., & Vernadat, F. (2008). Architectures for enterprise integration and interoperability: Past, present and future. Computers in Industry, 59(7), 647–659.

[5] Eppinger, S. D., & Browning, T. R. (2012). Design Structure Matrix Methods and Applications (p. 334). Cambridge, Massachussetts: The MIT Press.

[6] Fettke, P. (2008). Business Process Modeling Notation. Wirtschaftsinformatik, 50(6), 504–507.

[7] Huhns, M. N., Stephens, L. M., & Ivezic, N. (2002). Automating supply-chain management. Proceedings of the First International Joint Conference on Autonomous Agents and Multiagent Systems Part 3 - AAMAS ’02, (483), 1017.

[8] IDABC. (2010). European Interoperability Framework - Version 2.0. Retrieved from http://ec.europa.eu/idabc/servlets/Doc4ee4.pdf?id=18060

[9] IDEAS. (2003). IDEAS project Deliverables (WP1-WP7). Retrieved from www.ideas-roadmap.net

[10] IEEE. (1990). IEEE Standard Glossary of Software Engineering Terminology.

[11] Legner, C., & Lebreton, B. (2007). Business interoperability research: Present achievements and upcoming challenges. Electronic Markets, 49(341), 176–186.

[12] Legner, C., & Wende, K. (2006). Towards an Excellence Framework for Business Interoperability. In 19th Bled eConference eValues (pp. 1–16). Bled, Slovenia.

[13] Rezaei, R., Chiew, T. K., Lee, S. P., & Shams Aliee, Z. (2013). Interoperability evaluation models: A systematic review. Computers in Industry.

[14] Supply Chain Council. (2010). Supply Chain Operations Reference (SCOR) model - version 10.0 (p. 24). USA. Retrieved from supply-chain.org

[15] Tolk, A. (2003). Beyond Technical Interoperability – Introducing a Reference Model for Measures of Merit for Coalition Interoperability. In 8th International Command and Control Research and Technology Symposium.

[16] Vernadat, F. (1996). Enterprise modeling and integration: Principles and applications (1st ed., p. 513). London, United Kingdom: Chapman & Hall.

[17] Vernadat, F. B. (2010). Technical, semantic and organizational issues of enterprise interoperability and networking. Annual Reviews in Control, 34(1), 139–144.

[18] Wynn, D., Wyatt, D., Nair, S., & Clarkson, P. (2010). An introduction to the Cambridge advanced modeller. In Proceedings of the 1st International Conference on Modelling and Management of Engineering Processes (MMEP 2010) (pp. 19–20). Cambridge, UK, 19-20 July.