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Re-design of an interoperable buyer-seller automotive relationship aided by computer simulation

Pedro Espadinha-Cruz[a,]*, António Gonçalves-Coelho[a], António Mourão[a], António Grilo[a]

[a]UNIDEMI, Departamento de Engenharia Mecânica e Industrial, Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Campus Caparica, 2829-516 Caparica, Portugal

* Corresponding author. Tel.: +351-963507251. *E-mail address:* p.cruz@campus.fct.unl.pt

Abstract

Business Interoperability has become an indisputable reality for companies who cooperate and strive for competitiveness. Supply chain management is one kind of industrial cooperation that relies on large integration and coordination by interoperability factors, which until now is missing a tool to identify and solve its problems. The present article presents a systematic methodology applying axiomatic design theory and computer simulation to: study the impact of interoperability problems on dyad performance in terms of supply chain and interoperability; and the re-design of cooperation from the findings of the performance impact study. A case study applied in an automotive supply chain is presented to demonstrate the application of this method, mapping from the actual interoperability conditions ("as-is") to a scenario that guarantees higher levels of business interoperability ("to-be").

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Keywords: Business Interoperability; Axiomatic Design; Supply Chain Dyads; Computer Simulation

1. Introduction

Business interoperability (BI) is an organizational and operational ability of an enterprise to cooperate with its business partners and to efficiently establish, conduct and develop information technology (IT) supported business with the objective to create value [1]. In the context of supply chain management (SCM), business interoperability is an enabler that makes possible to execute the SC operations seamlessly, easing their alignment and the information flow, guaranteeing high performance and competitiveness. The supply chain operations reference model (SCOR) [2] makes a link between performance measures, best practices and software requirements to business process models [3]. However, the SCOR model does not show how to proceed to achieve interoperability.

On our research, we aim at the research question "How to achieve high levels of interoperability in supply chain dyads?", addressing one-to-one relationships in supply chains. To approach this issue, we address three topics: characterization and analysis of interoperability problems; cooperation re-design; and the study of the interoperability impact in the dyad performance. This work proposes a method to represent interoperability conditions and the means to re-design cooperation based on the study of the impact on the dyad performance (in terms of SCM and interoperability performance).

The article is structured as follows: section two makes a brief review on the key topics; section three describes the methodology for analyzing and re-designing the supply chain dyadic cooperation; section four presents a case study on an automotive supply chain dyad; and section five presents the conclusions.

2. Business Interoperability

BI is a concept that evolved from the technical perspective of interoperability incorporating several aspects of organization interactions. Frameworks and researches like IDEAS [4], INTEROP Framework [5], [6], ATHENA Interoperability Framework (AIF) [7], ATHENA Business Interoperability Framework (BIF) [7] and European Interoperability Framework (EIF) [8], [9] traced the evolutionary path that led to the exiting notion of business

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interoperability. In previous work from [10], several kinds of interoperability that contribute to the current definition of business interoperability were identified and related. The different perspectives of interoperability reflect the issues that one must attend to achieve higher levels of interoperability or, as it was defined by [10], achieve "optimal interoperability".

3. Methodology to analyze and re-design dyadic cooperation

The proposed method to analyze and re-design the supply chain dyads is depicted in Fig. 1.

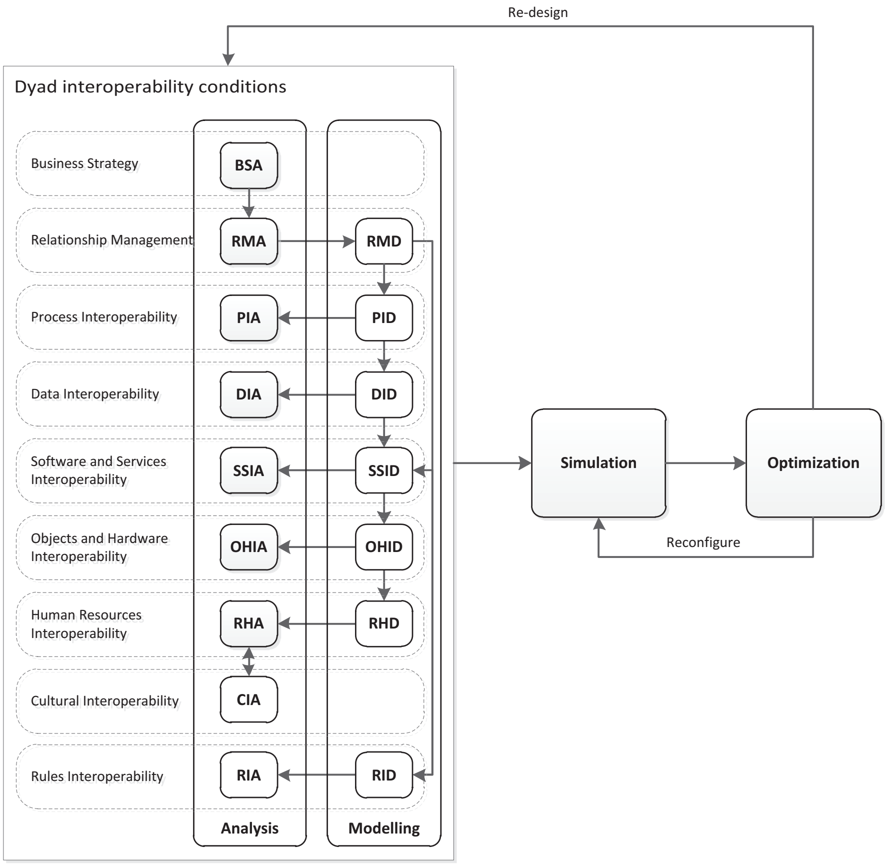


Fig. 1. Methodology to analyze and re-design dyadic cooperation [11].

In this method, the first phase is to analyze and model the dyad interoperability conditions in terms of the business interoperability components that represent the "as-is" situation. On the second stage, one simulates the "as-is" model and identifies the various scenarios that may lead to a more interoperable situation. In this matter, we propose two kinds of approach: an improvement of the current scenario by addressing the interoperability variables that one can change in order to reconfigure the relationship (for instance, the human resources quantity on a specific process); or the re-design of certain aspects of interoperability, such as the process design or the selection of another information system that permits improving the dyad performance. In the last stage (optimization stage), is selected the scenario that has the best performance in terms of interoperability and in terms of supply chain performance.

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 modeling the interoperability components in a process that we call analysis and decomposition stages (see Fig. 1). 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 relationship management that impact subsequent components.

In the application of the present method, there are two kinds of stages to determine the interoperability conditions on the dyad: analysis and decomposition. The analysis stages (A stages) are evaluated according to the levels of interoperability, which correspond to a level of business sophistication or maturity that is considered optimal or near optimal in terms of interoperability. This approach follows the research done on the level of interoperability assessments (e.g. [12]–[14]), and maturity levels (e.g. [16,17]).

The decomposition stages (D stages) refer to the detail of the interoperability conditions, by means of axiomatic design decomposition (vertical decomposition), and using external modelling tools such as Design Structure Matrix (DSM) [17], Business Process Modelling Notation (BPMN) [18] applied to the supply chain modeling.

The simulation and optimization are the final stages that link the interoperability conditions with the dyad performance. Supply chain performance metrics and interoperability metrics are applied here to infer about the dyad behavior in terms of business inherent metrics (supply chain) and in terms of the utilization of systems. In the next section we present a case study that is currently being developed on an automotive supply chain. To evaluate the two companies three performance metrics were selected: order lead-time [19]–[23], time of interoperation and conversion time [7], [20,21], [34], [35].

4. Case study

The present case study was applied in two automotive suppliers operating as 1st tier and 2nd tier supplier towards 39 automotive manufacturers. The 2nd tier supplier (SS1) provides copper wire in order to the 1st tier supplier (FS) produce injection coils for its customers. The development of this case study was according to the methodology in Fig 2. However, for simplification purposes, the present results refer to business strategy (BS), relationship management (RM) and process interoperability (PI) components of interoperability. Data interoperability (DI), software and services interoperability (SSI), objects and hardware interoperability (OHI) and human resources (HR) are not addressed in detail in the current case study. We refer to them as resources for the business processes taken place by both companies (generally in DPs and PVs).

Through interviews, questionnaires and by analyzing the documentation of the companies, it was determined the interoperability conditions in the dyad. The main customer need (CN) is to ‘achieve higher business interoperability in the design of the buying-selling relationship’. That one we proposed to achieve by ‘ensuring high levels of interoperability in the purchasing-selling interactions’ (FR_0) through a ‘systematic design of the dyad’ (DP_0).

The first condition to assess was the business strategy (BS). The FRs for establishing the cooperation goals for the dyad (FR_1) are the following:

- $FR_{1.1}$: Establish well-defined delivery conditions and liabilities.
- $FR_{1.2}$: Reconcile the actors' individual strategy with the cooperation strategy.
- $FR_{1.3}$: Avoid failures in cooperation.

According to $FR_{1.1}$, both partners must agree on the objectives to set up cooperation. On the existing conditions ("as-is") both companies fulfilled a written agreement spelling the conditions of purchase and supply ($DP_{1.1}$). Although a revision of competencies was fulfilled previously to the agreement, the conditions were strongly imposed by the governing company: FS. For this interoperability aspect, the companies were questioned about the form the objectives were established and both disagreed. FS considers that the objectives were previously agreed in a clear manner by reviewing the supplier competencies and capabilities. But, in opposition, SS_1 considers that the agreement wasn't settled envisioning a mutual advantage relationship. Hence, the DPs, and PVs for the dyad are presented in Table 1.

Table 1. BS dyad interoperability conditions.

$DP_{1.1}$: Written contract specifying the delivery conditions and liabilities.	$PV_{1.1}$: The delivery lead-time allotted to the purchase orders is 7 days (5 working days).
$DP_{1.2}$: Cooperation strategy was defined, but it is not aligned with the individual objectives.	$PV_{1.2}$: Negotiate penalties in case of failure to the commitments.
$DP_{1.3}$: Both actors know the cooperation strategy.	$PV_{1.3}$: Follow the cooperation objectives and liabilities specified in the contract.

The resulting design matrix (see Fig. 3) for FRs and DPs was decoupled. The design of the business strategy for the dyad is coupled because the establishment of the cooperation goals didn't take into account their individual capabilities and resources leading to conflicts in cooperation, explaining the decoupled design. To satisfy the first axiom, the design should be uncoupled. The suggested top levels for business strategy would lead to an adequate solution in terms of interoperability. The DPs that fit the highest level of BS interoperability are the following:

- $DP_{1.1}$: All the competencies and capacities were reviewed in order to establish a mutual advantage business relationship.
- $DP_{1.2}$: The competencies were fully reviewed to avoid interest conflicts.
- $DP_{1.3}$: The strategic objectives were fully aligned. It was established a strategic partnership and both partners review constantly the competencies striving for competitive advantage.

These ones allow companies to achieve an uncoupled design.

The second functional requirement proposed to address business interoperability in dyads is to ‘manage cooperation’ (FR_2) through the ‘implementation of measures to maintain cooperation’ (DP_2).

Regarding dyad governance ($FR_{2.1}$), FS is notably the governing firm. Both companies agree that whatever decisions FS takes will affect SS1.

Responsibility assignment is an issue reflected on $FR_{2.2}$. This issue affects directly the process distribution internally and on the interface processes (addressed in FR_3). The assessment for this issue is the highest level of interoperability, considering that there are no responsibility gaps and the role assignment is adequate (dependency between FRs and DPs for $FR_{2.2}$ is uncoupled - see Fig. 3).

The partner selection ($FR_{2.3}$) was performed by FS according to a pre-selection of the FS corporate group companies. The evaluation of this aspect is medium, referring to the selection of a certificated supplier, rather than the broad assessment of the competences performed by FS, which is the maximum interoperability level for this aspect.

To monitor cooperation the following strategic and tactical performance metrics are suggested: order lead-time (OLT), supplier lead-time compared to contract, total time of interoperation (TIP) and wasted time in information conversion (Cv).

In sum, the FRs for FR_2 are the following:

- $FR_{2.1}$: Distribute governance in the dyad.
- $FR_{2.2}$: Assign actors to business activities.
- $FR_{2.2.1}$: Assign responsibilities to the supplier.
- $FR_{2.2.2}$: Assign responsibilities to the focal firm.
- $FR_{2.3}$: Manage cooperation in its initiation.
- $FR_{2.4}$: Monitor cooperation.
- $FR_{2.5}$: Ensure the partners have the adequate skills to perform SC activities.

The DPs and PVs for FR_2 are presented in Table 2.

Table 2. RM dyad interoperability conditions.

$DP_{2.1}$: Unilateral power distribution	$PV_{2.1}$: FS is the governing firm and all decisions affect directly SS_1.
$DP_{2.2}$: The identification of role assignments and its level of adequacy and possible existence of responsibility gaps.	
$DP_{2.2.1}$: Well-defined. The responsibility and roles assignment is not an issue.	$PV_{2.2.1}$: SS_1 is responsible for receiving orders from the focal firm, produce, pack and deliver the goods in the specified times and supporting all the costs.
$DP_{2.2.2}$: Well-defined. The responsibility and roles assignment is not an issue.	$PV_{2.2.2}$: FS places orders, delivers the production schedules and forecasts, manages the relationship by monitoring it onsite, receives the goods and makes the payments.
$DP_{2.3}$: Selection of a certified supplier.	$PV_{2.3}$: SS_1 was selected according to the FS corporate group rating and evaluations.
$DP_{2.4}$: Strategic internal business, business relationships and customer service dimensions and tactical SCM and interoperability performance metrics.	$PV_{2.4}$: The values of the performance metrics on as-is and DPs alternatives.
$DP_{2.5}$: Appropriate skills for cooperation.	$PV_{2.5}$: The training and competences are a requirement assessed during the sourcing and supplier selection phase.

The third functional requirement refers to the process interoperability (PI) analysis and decomposition. Unlike FR_1 and FR_2, FR_3 is approached not only using levels of interoperability, but also are modeled using BPMN, DSM and computer simulation. This approach permits to model and to test the modeling without resourcing and interfering in the real system. Thus, the main FR for PI is to 'manage internal and interface processes on cooperation', by establishing a 'collaborative business process' (DP_3). These ones are decomposed into the following FRs:

- $FR_{3.1}$: Model and manage FS processes.
- $FR_{3.1.1}$: Model the process sequence of FS processes.
- $FR_{3.1.2}$: Manage the interface between the inventory management system and the ordering system.
- $FR_{3.1.3}$: Align purchasing and reception with FS organizational structure.
- $FR_{3.2}$: Model and manage SS_1 processes.
- $FR_{3.2.1}$: Model the process sequence of SS_1 processes.
- $FR_{3.2.2}$: Manage the interface between the ICT for order reception and the order management system.
- $FR_{3.2.3}$: Align SS_1 processes with organizational structure.
- $FR_{3.3}$: Align companies' internal processes.
- $FR_{3.3.1}$: Manage the order placement procedure.
- $FR_{3.3.1.1}$: Assign employees to the interface for order placement/reception.
- $FR_{3.3.1.2}$: Manage the interface between order management systems.
- $FR_{3.3.1.3}$: Manage the communication path to place orders.
- $FR_{3.3.2}$: Manage the order confirmation procedure.
- $FR_{3.3.2.1}$: Manage the communication path to confirm orders.
- $FR_{3.3.2.2}$: Manage the interface between ICT's used to confirm orders.
- $FR_{3.3.3}$: Establish a delivery process for material flow.
- $FR_{3.4}$: Select metrics to monitor processes.

The DPs and PVs for FR3 are presented in Table 3.

Table 3. PI dyad interoperability conditions.

$DP_{3.1}$: FS actual business process model (BPM) for purchasing (see "parts ordering" pool in Fig. 2).	
$DP_{3.1.1}$: Sequential procedures with low interaction.	$PV_{3.1.1}$: Independent processes. Interaction occurs mainly between users and systems.
$DP_{3.1.2}$: SAP and e-mail are not interoperable requiring manual conversion.	$PV_{3.1.2}$: One user checks MRP on SAP and prepares an e-mail to send purchase orders (POs).
$DP_{3.1.3}$: Functional process distribution matching a process to a section.	$PV_{3.1.3}$: Parts ordering section for order placement and validation activities; and reception to treat the material arrivals.
$DP_{3.2}$: SS_1 actual BPM for order reception and treatment (see "sales/logistic" pool in Fig. 2).	
$DP_{3.2.1}$: Cooperative procedure between logistics planning and production planning.	$PV_{3.2.1}$: Sales procedure starts the processes and interacts directly with production planning, requiring cooperation modelling.
$DP_{3.2.2}$: E-mail and SAP are not interoperable. Order data must be inserted manually into SAP.	$PV_{3.2.2}$: A user checks e-mail and inserts order manually.
$DP_{3.2.3}$: Many tasks performed by one section).	$PV_{3.2.3}$: Sales section employee performs manual conversion, selling and logistics activities. The rest procedure has dedicated sections.
$DP_{3.3}$: The interface BPM (see Fig. 2).	
$DP_{3.3.1}$: Features of order placement.	
$DP_{3.3.1.1}$: Contact points defined.	$PV_{3.3.1.1}$: User from parts ordering is exclusive to contact SS_1.
$DP_{3.3.1.2}$: Order data is not compatible between firms.	$PV_{3.3.1.2}$: Manual entry of order data.
$DP_{3.3.1.3}$: Standard procedure defined to communicate orders.	$PV_{3.3.1.3}$: One user from FS sends order data by e-mail. Another user from SS_1 receives it, and processes order.
$DP_{3.3.2}$: Features of order confirmation.	
$DP_{3.3.2.1}$: Standard procedure to communicate.	$PV_{3.3.2.1}$: The user from sales and logistics section confirms orders by EDI sending and ASN.
$DP_{3.3.2.2}$: ASN is integrated directly on SAP system.	$PV_{3.3.2.2}$: User from parts ordering review daily the order confirmations.
$DP_{3.3.3}$: 3rd party freight forwarder to deliver materials.	$PV_{3.3.3}$: Materials retrieved from SS_1 and delivered to FS in 2-3 days.
$DP_{3.4}$: Time dimension supply chain and interoperability metrics to assess sourcing and delivery operations.	$PV_{3.4}$: Measurement of order lead-time (OLT), time of interoperation (TIP) and wasted time in conversion (Cv).

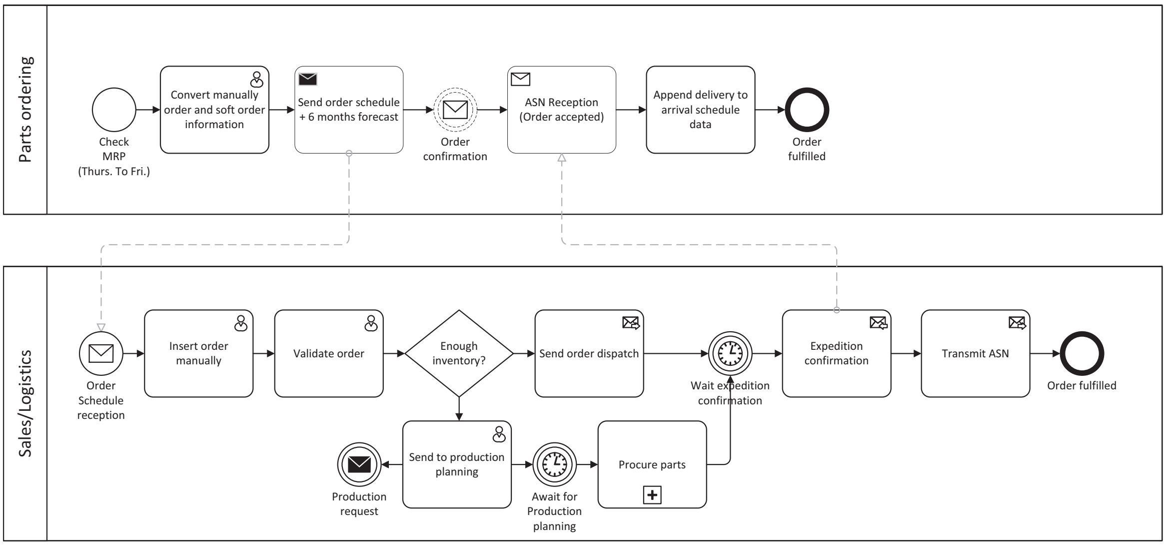


Fig. 2. Business process model for the current dyad interface.

In sum, the design matrix for the "as-is" dyad condition is presented in Fig. 3.

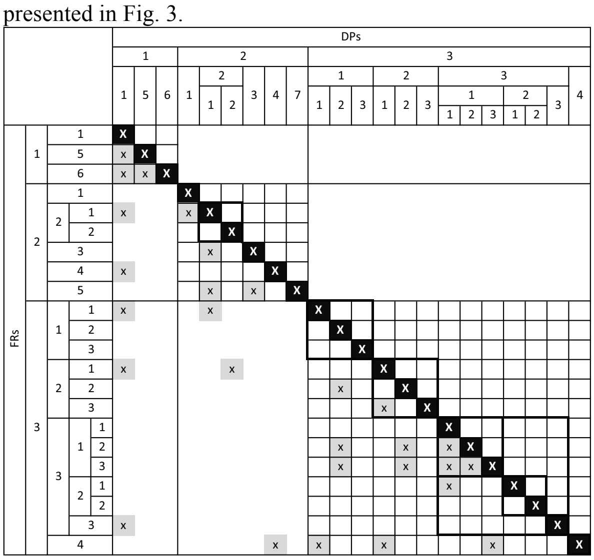


Fig. 3. Design matrix for the "as-is" interoperability conditions.

By analyzing and representing the companies individual processes, was possible to identify interoperability problems due lack of systems interoperability.

$DP_{3.1.2}$, $DP_{3.2.2}$, $DP_{3.3.1.2}$ and $DP_{3.3.1.3}$ correspond to the design approach for the companies deal with the interface between the order management system SAP and information and communication technology (ICT) – internally – and the interface between each SAP – on the interface. The order management system in both companies is the same (SAP software), but the used ICT makes data incompatible between SAP and ICT, and between the SAP from both companies.

To overcome this interoperability problem, we suggest the following alternatives:

1. Optimize the PVs associated with the DPs of the "as-is" situation;
2. Implement a WebEDI solution, acting on $FR_{3.1.2}$ by making the SAP and ICT interoperable;
3. Implement an Electronic Data Interchange (EDI), acting on all the DPs simultaneously making the data compatible between the two companies.

Using the gathered information form the firms, a simulation model was built, using Rockwell Arena Software [28], representing the dyad processes. Figure x presents the generic processes modeled in the simulation model. However, from those operations, we obtained the results from the interaction between the SS1's sales and logistics section and FS's parts ordering.

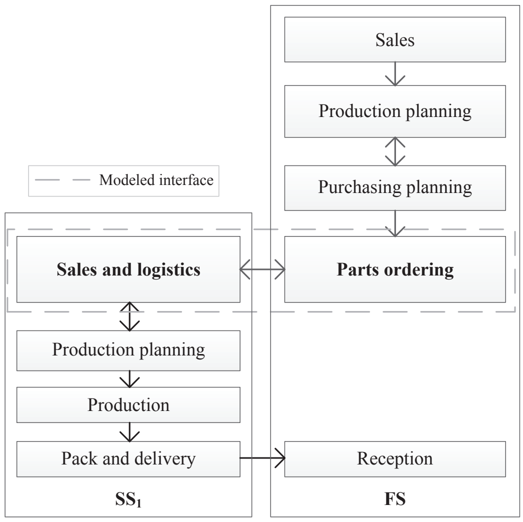


Fig. 4. Generic view of the simulated processes using Rockwell Arena Software[28]. .

The simulation model was initialized with the final costumers demand obtained from FS data. The replication length is 2 years, the number of replications is 20 and the warm-up period is 480 hours. The values were obtained with 0,09% error and a confidence interval of 99%.

The improvement of the "as-is" conditions consisted in determining the adequate human resource distribution in the activities that have interoperability problems. Namely, the manual conversion of data in $DP_{3.1.2}$ and $DP_{3.2.2}$, is executed according to $PV_{3.1.2}$ and $PV_{3.2.2}$. The graphic in Fig. 4 shows the variation of OLT in terms of hours with the resource distribution. The values on abscissa axes represent the SS_1 resource distribution and process arrangement, since the current ("as-is") situation whereas only one employee performs the activities sequentially, to the increasing of employees (since 1 as the existing up to 3), considering that the conversion procedure is done separately from the subsequent activities, using the existing employee, and exclusively by additional employees that perform only the manual insertion of orders. Regarding the FS, the changes on employees' quantities are represented by each series on Fig. 4, and correspond to adding new employees to the existing ones.

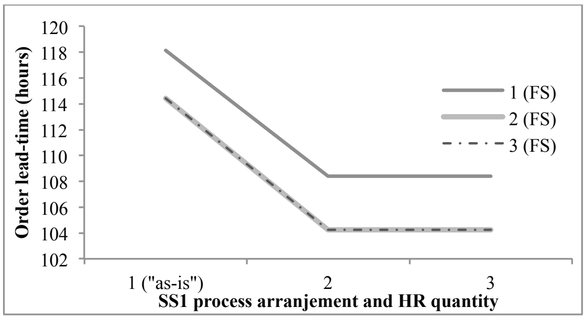


Fig. 5. Order lead-time values in function of process rearrangement and additional human resources in both companies in the "as-is" model.

In alternatives 2 and 3, WebEDI and EDI were implemented, corresponding to new DPs that solve the incompatibility between SAP and ICT. Though, the PVs were also improved in a similar manner as in the "as-is". In alternative 2, best results for the WebEDI implementation were obtained by contracting 2 employees, one in each company (see Fig. 6).

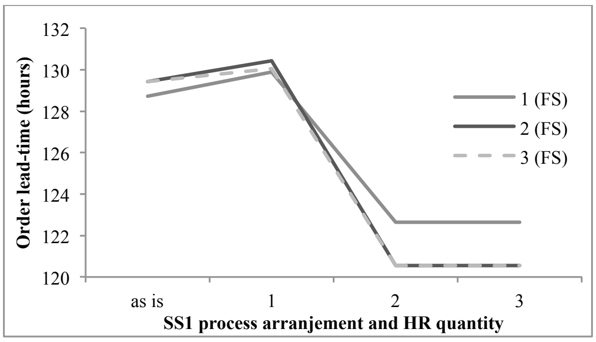


Fig. 6. Results for WebEDI implementation.

The results for alternative 3 are presented in Fig. 7. The best values of OLT are obtained contracting one employee to help in the "parts ordering" processes, and another to "sales and logistics" processes.

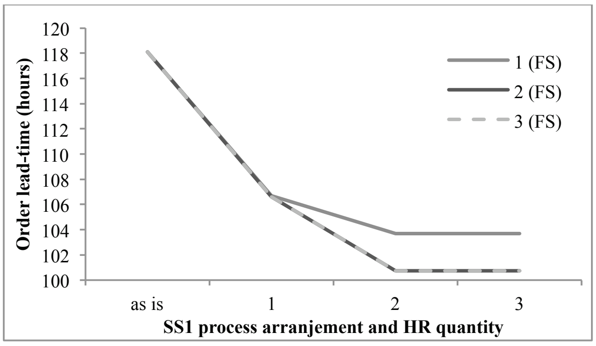
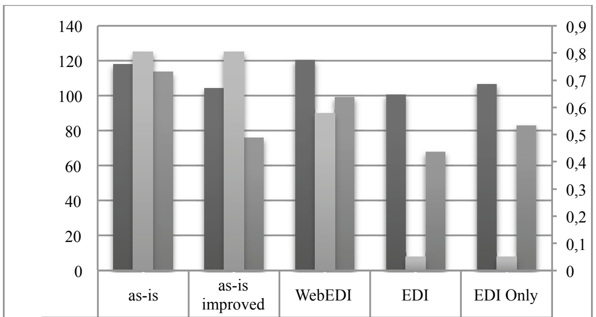


Fig. 7. Results for EDI implementation.

Comparing the alternatives, the best solution to improve interoperability in the dyad is the implementation of the EDI (see Fig. 8), where we reduce the OLT in approximately 18 hours, the TIP in 46 hours and the Cv in 0,755 hours (45 minutes).



	as-is	as-is improved	WebEDI	EDI	EDI Only
OLT	118,12	104,246	120,547	100,733	106,698
TIP	113,577	76,021	99,28	67,98	83,05
Cv	0,805	0,805	0,578	0,05	0,05

Fig. 8. Supply chain and interoperability performance measures for the analysed scenarios.

However, the optimization of the "as-is" conditions (see "as-is improved" on Fig. 5), permit a reduction of 14 hours in OLT, and 37 hours in TIP. This may be achieved by adding 1 employee in each company, like in the optimization of the EDI. This means that to implement the EDI and achieve optimal results, we need to invest in an EDI connection and the contracting of two additional employees.

In terms of business processes, both companies need to adopt a new business process model to implement the EDI (see Fig. 9). Instead of converting manually the order data in order to be exchangeable and usable between firms, when FS creates a new purchase order this one is instantly sent by EDI and integrated in SS_1's SAP system. Though, in order to obtain best results in terms of OLT, Cv and TIP, the work methods associated to ICT and SAP interfaces ($FR_{3.1.2}$ and

$FR_{3.2.2}$) require the use of additional employees in a different human resource distribution.

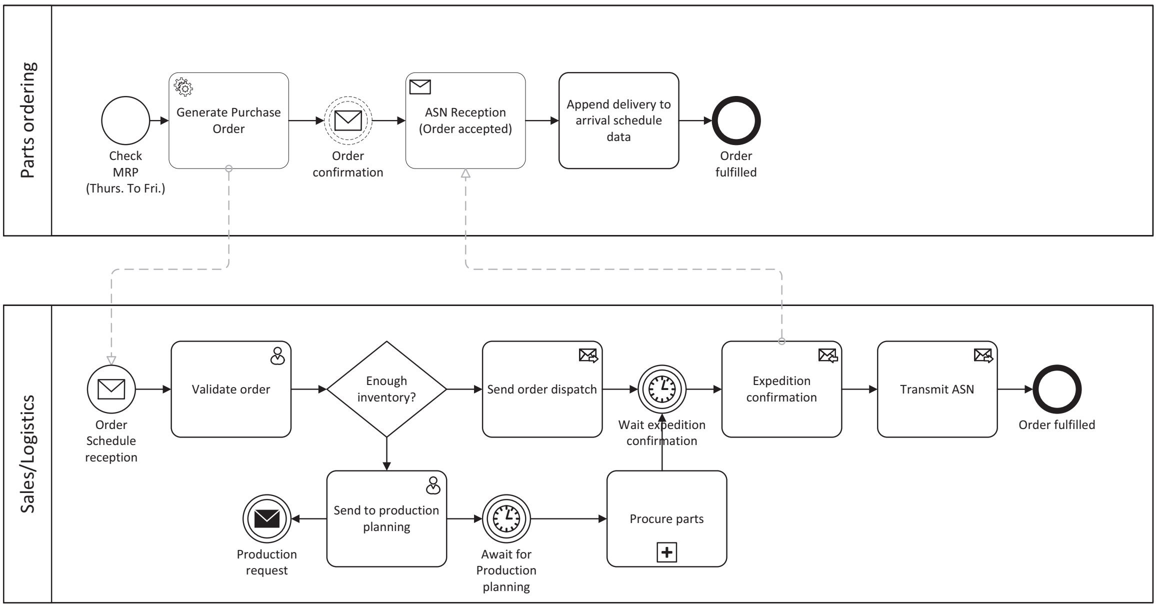


Fig. 9. BPM for the EDI implementation on the dyad.

In sum, the implications on the design are presented in Table 4 and in Fig. 10.

Table 4. DPs and PVs for EDI implementation on the dyad.

$DP_{3.1}$: FS BPM for purchase and reception using EDI to send purchase orders (see "parts ordering" pool in Fig. 9).	
$DP_{3.1.2}$: SAP and EDI are interoperable.	$PV_{3.1.2}$: Two users check MRP on SAP and generate purchase orders (POs).
$DP_{3.2}$: SS_1 BPM for order reception, treatment, production and delivery (see "sales/logistic" pool in Fig. 6).	
$DP_{3.2.2}$: EDI and SAP are interoperable.	$PV_{3.2.2}$: Two users validate the purchase orders on SAP.
$DP_{3.3}$: Collaborative business process model applying EDI for order placement (see Fig. 6).	
$DP_{3.3.1.2}$: Order data is compatible between firms.	$PV_{3.3.1.2}$: Data is seamlessly exchanged between SAP systems.

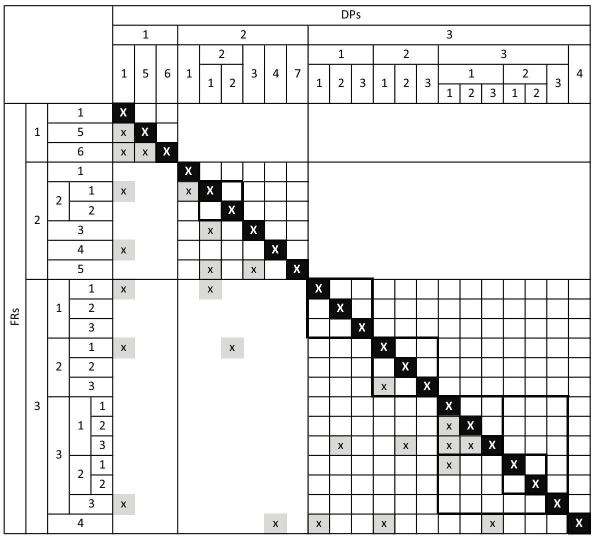


Fig. 10. Final "to-be" design of the dyad.

5. Conclusions

The present article proposes and demonstrates how to integrate different business interoperability aspects supply chain dyads, tracking interoperability conditions from strategic decisions to the information technology based process execution measuring its impact on dyad performance.

Through the presented case study was possible to identify interoperability problems at the business strategy component, whereas was determined that the dyad companies didn't established a mutual agreement. This is demonstrated by the coupling on the FR1 decomposition matrix.

On FR3 the dyad processes were assessed and were presented the results that improve cooperation by optimizing the resource use on the processes and by changing the information and communications technology (ICT) to exchange data between companies. According to the selected performance measures, the EDI is the best solution if implemented with two additional employees, one in each company, having the possibility to decrease the OLT by 18 hours, the TIP by 45 hours and the Cv by 48 minutes.

Future work will concentrate on the integration of other interoperability aspects by implementing Design of Experiments and Taguchi methods. This will allow us to deal with the complexity of Business Interoperability by systematizing the influence of interoperability aspects on performance.

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