Proceedings of ICAD2013
The Seventh International Conference on Axiomatic Design
Worcester – June 27-28, 2013
ICAD-2013-24

THE DESIGN OF AN INTEROPERABLE SELF-SUPPORTED REVERSE LOGISTICS MANAGEMENT SYSTEM

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ABSTRACT

Green Supply Chain Management (SCM) strategies emerged as a response to business competition with commitment to the environment. Reverse Logistics is part of this strategy that allows materials and products to be returned for re-use, re-manufacture or re-furbishing, requiring effective and efficient cooperation between supply chain (SC) firms. However, the lack of interoperability affects the alignment of operations with partners. This work presents a methodology to design the cooperation between partners using the systematic approach that is provided by Axiomatic Design Theory and a case study to demonstrate the application of this method to design a self-supported reverse logistics management system.

Keywords: reverse logistics, green supply chain management, business interoperability, Axiomatic Design.

1 INTRODUCTION

Due to the current market situation, the fierce competition between companies requires innovative strategies committed with the environment. Green Supply Chain Management (GreenSCM) strategies emerged as a response to environmental changes, guaranteeing environmental excellence in business activities [Srivastava, 2007]. In this context, Reverse Logistics (RL) arose as a solution to assign value to non-valued products or materials [Lau and Wang, 2009]. Therefore, this practice has the challenge of coordinating, effectively and efficiently, operations and material flows with regular business activities. For this reason, the latest achievements in business interoperability research combined with Axiomatic Design Theory allow us to describe how to establish reverse logistics cooperation, from top strategy issues to data transactions supported by information technology. This work presents a method to design an interoperable dyadic relationship with the purpose of applying reverse logistics between a first tier supplier and a focal firm that can manage alone the reverse logistics activities.

The work is structured in the following sections: section two contains a review of key topics (reverse logistics and business interoperability); section three describes the method and the background research that inspired the presented design; section four describes in detail the design of a dyadic reverse logistics relationship between a focal firm (manufacturer) and a first tier supplier; and, section five presents the final conclusions and comments related to the described design and outlines the main contributions and goals to achieve in future research.

2 LITERATURE REVIEW (KEY TOPICS)

2.1 REVERSE LOGISTICS

Reverse logistics (RL) refers to the physical flow of discarded materials that have lost their original value [Shi *et al.*, 2012]. It involves all the operational aspects related to collection, inspection, pre-processing and distribution associated with green manufacturing (reduce; recycle; production planning and scheduling; inventory management; remanufacturing, material recovery) and waste management (source reduction; pollution prevention; disposal) [Srivastava, 2007]. From a strategic point of view, RL has a high relevance to business. Srivastava [2007] stresses that investments in GreenSCM strategies like RL can be resource saving, waste eliminating and productivity improving. But, on other hand, the high cost of reverse logistics also compels firms to look at the issue seriously from a long-term strategic perspective [Lau and Wang, 2009].

The complexity of flows in RL leads to a diversity of return routes from end customer to raw materials suppliers (see Figure 1), making it hard to coordinate with forward logistics activities. Unlike the forward chain, there are many more sources of raw materials and they enter the reverse chain at a small cost or at no cost at all, and with high uncertainty of supply (collection) [Kot and Grabara, 2009]. In their work, Lau and Wang [2009] present three configurations for the RL networks: self-supported reverse logistics model;

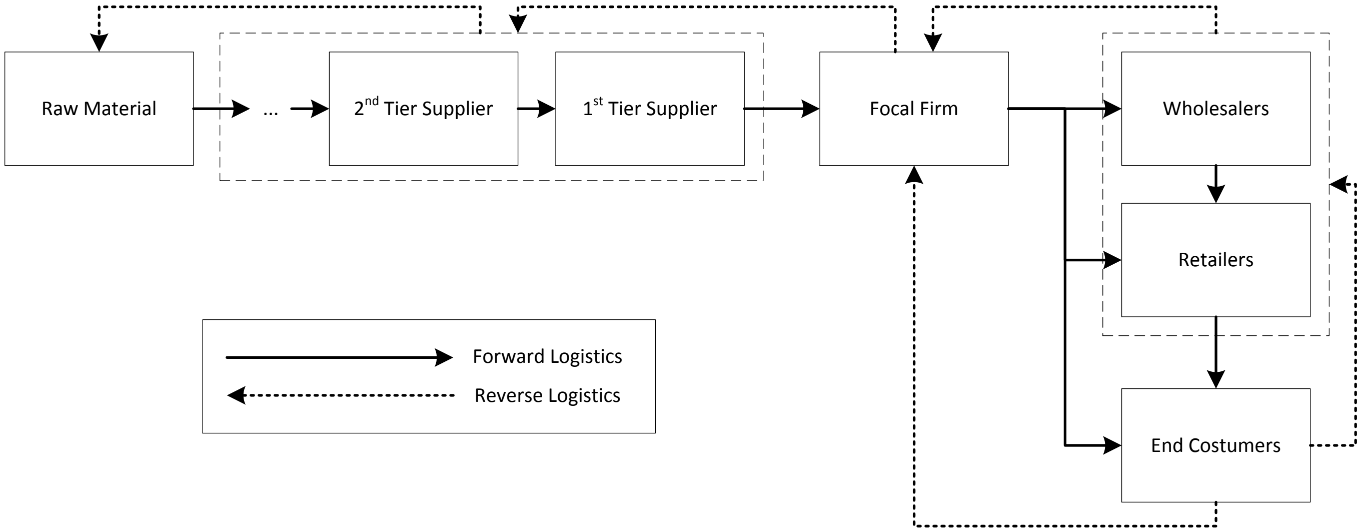

Figure 1. Forward and reverse logistics flows (adapted from Srivastava [2007]).

third-party reverse logistics (3PRL) model and collaborative reverse logistics model.

A self-supported RL management system helps firms collect valuable information about its products for continuous improvement ([Smith, 2005], cited by Lau and Wang [2009]). However, self-supported RL management systems involve significant capital investment [Lau and Wang, 2009]. On the other hand, a collaborative approach to manage and perform RL is less expensive, involves lower investment, and enables economies of scale through centralization [Lau and Wang, 2009].

A third conformation for RL network is suggested by the same authors. This approach allows a firm to focus on its core activities as well as to achieve more flexible reverse logistics operations and to transfer risk to third party [Lau and Wang, 2009].

2.2 BUSINESS INTEROPERABILITY

Business interoperability was introduced by Legner and Wende [2006], who defined it as "the 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". Far from the technical perspective initially defined by IEEE [1990], this concept has evolved from syntactic and semantic perspectives to a more pragmatic position, concerning not only the interactions with the information systems, but also the organizational point of view. Initiatives like ATHENA [2007; Berre et al., 2007], the European Interoperability Framework (EIF) [IDABC, 2010], ECOLEAD [Consortium and others, 2006], Levels of Information Systems Interoperability (LISI) [DoD, 1998], Levels of Conceptual Interoperability Framework (LCIF) [Tolk and Muguira, 2003] and IDEAS have defined a possible path to achieve "optimal interoperability" [ATHENA, 2007] in electronic systems and businesses. Such frameworks provided data to achieve interoperability in three layers: business, knowledge, and information and communications technology (ICT) systems.

These three layers become a common concern in the context of the above-said frameworks, specifically in the definition of the business interoperability parameters (BIP), as proposed by Zutshi *et al.* [2012] and Zutshi [2010]: 1) business strategy (BS), 2) organizational structures (OS), 3) employees and work culture (EWC), 4) collaborative business processes (CBP), 5) management of external relationships (MER), 6) intellectual property rights management (IPRm), 7) business semantics (BSe) and 8) information systems (IS). These eight parameters represent the driving forces of collaboration between organizations, and allow analysing business-to-business (B2B) relationships that are suitable to SC's relationships between actors [Espadinha-Cruz *et al.*, 2012; Espadinha-Cruz, 2012]. The role of these parameters in the current work is to provide the main guidelines to decompose business activities into each BIP perspective.

3 METHOD AND AIM

The design herein depicted intends to provide solutions to problems identified by Espadinha-Cruz *et al.* [2012] and Espadinha-Cruz [2012] in a case that pertains to a Portuguese automaker. Those authors developed a business interoperability assessment methodology to analyse the implementation of reverse logistics with a first tier supplier. Their study unveiled some difficulties at the strategic, operational and information issues, since they found that it was lacking interoperability at some BIPs. Specifically, BS, EWC, CBP, MER, BSe and IS required a substantial revamping in order to take their interoperability to a condition that could be considered appropriate for the implementation of RL. The analysed automaker understands the importance of RL to the business goals, however some conditions are lacking. For instance, it is missing a business process to rule the RL activities. As consequence, issues like IS, MER, and EWC, have no guidelines to be established, and the occurrence of a rework, remanufacture or disposal is planned in each case.

Axiomatic Design (AD) Theory [Suh, 1990] provides an appropriate method to develop a systematic approach to fulfil the objectives of RL and the business interoperability requirements. This method permits us to describe in detail the dyadic relationship, committing design parameters (DP) to functional requirements (FR) along the diverse levels of the design decomposition: the business interoperability parameters. These parameters rule the interaction between two or more companies and should be included in the design of relationships, to reflect the design solution to each interoperability aspect. Although AD is often regarded just as one more engineering design tool, the literature shows that it can be used to design business platforms of diverse kinds. For instance, dos Santos *et al.* [2011] describe an Axiomatic Design approach to the design of a new business oriented to venture capital fundraising. This research led to interesting results, proving that AD is a useful approach to setup businesses focused on financial issues.

4 DESIGN OF SELF-SUPPORTED REVERSE LOGISTICS BETWEEN FOCAL FIRM AND 1ST TIER SUPPLIER

4.1 CUSTOMER NEEDS (CN) CHARACTERIZATION

The focus of this project is the dyad between a focal firm and a 1st tier supplier of an automotive supply chain. The customer is the focal firm that wants to establish a cooperation procedure and an IT system to allow the implementation of RL with a supplier for a specific product that represents most of the production value. However, as mentioned in section 2.1, there are three possible configurations for the RL networks. So, for this relationship three possible case studies are considered: CS_1 - self-supported reverse logistics model; CS_2 - collaborative reverse logistics model and CS_3 - third-party reverse logistics (3PRL) model. For the present design, it is assumed the situation of CS_1, in which the focal firm can manage alone the RL operations constraint, and support its costs, only needing to assign the re-manufacturing activities to the supplier. On the other hand, the supplier can guarantee the re-manufacturing of slightly damaged products.

4.2 PROCESS DESCRIPTION

The RL process is made of 5 main activities: collection, inspection, pre-processing, location and distribution and re-manufacturing. In the presented scenario, the focal firm has the ability to manage RL. Thus, is responsible for the first 4 activities, performing the collection of items, inspecting them in order to evaluate and deciding how and whom will recover the items. Additionally, in the pre-processing, the focal firm makes the preparation of the item to be recovered or disposed. In other words, it repairs and disassembles the components and processes waste before disposal. The supplier is only responsible for re-manufacturing and receiving the disassembled component.

The main concerns of the business correspond to the frontier of the responsibility. The effectiveness material and information flows and the coordination of activities rule the performance of RL. Figure 2 illustrates the generic processes (material flows) of the supplier and focal firm, referring to the interface activities between these actors.

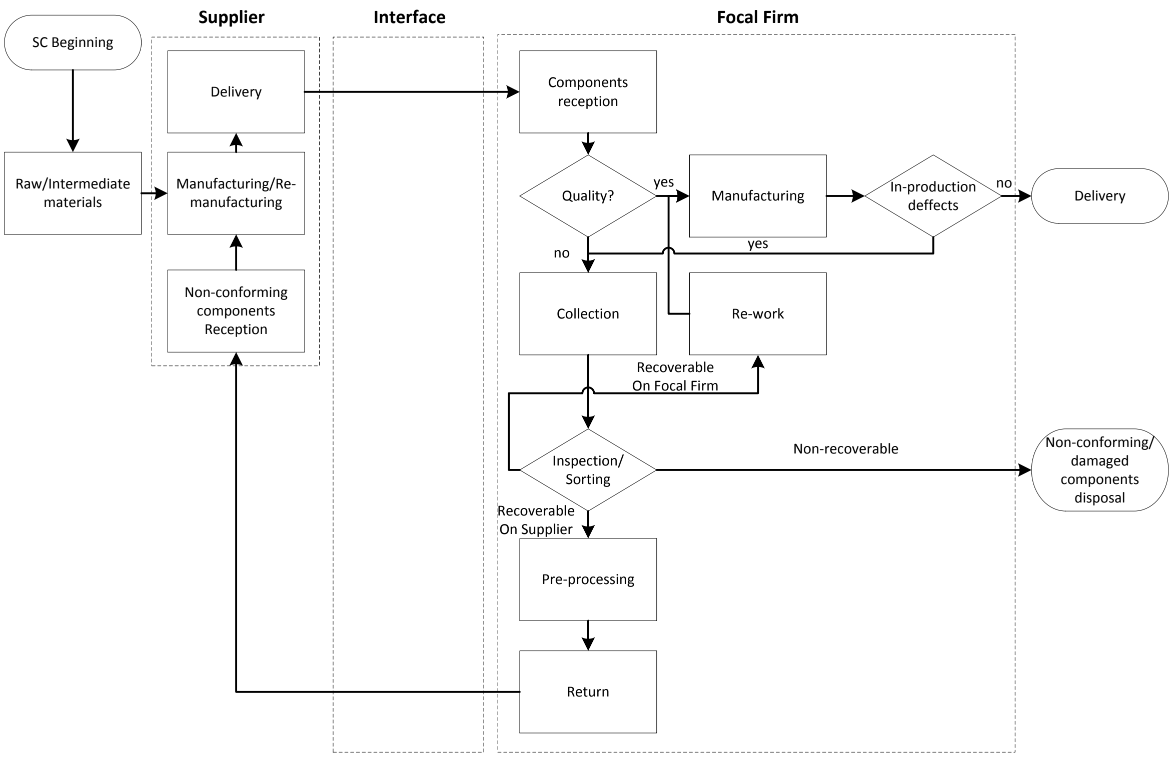

Figure 2. RL generic activities inherent to a self-supported RL management configuration.

The project of this relationship acts precisely at the interface between the two companies, addressing materials, data and currency flows, as well as human collaboration.

4.3 Definition of Highest Level Design Objectives

In the perspective of AD, the functional requirement of order zero (FR_0) is to ensure interoperability in the implementation of reverse logistics, which is achieved if the level 1 functional requirements are fulfilled. For this design, the following was selected as the highest level FR:

FR_0: Ensure interoperability in the implementation and management of reverse logistics.

In order to fulfil FR_0, the design parameter DP_0 will be:

DP_0: RL partnership.

The RL partnership (DP_0) success will be achieved if the measures of success, such as recovery, return, defect and scrap rates, cycle times, inventory turns, repair, remanufacturing and refurbish costs, etc. are satisfied.

4.4 Definition of Top Level FRs and DPs

The strategic focus of RL is translated by clarity in the cooperation goals for both companies. It stresses the main objectives, agreements and contracts that settle the arrangement on formal conditions. For this business perspective, the needed requirements fit in the following:

FR_1: Establish the cooperation goals to implement RL with the selected supplier.

The management of business processes is related to the development of the business activities, in order to ease material flow between partners. Thus, the main requirements in this subject are translated in:

FR_2: Establish business processes to ease reverse material flows.

Business relationships must be of concern from contract initiation until termination. The efficient management of interests and partnership behaviour will allow the growth of a trustworthy relationship that will bring the most advantages to RL performance. Hence, the functional requirement for this set of requirements is:

FR_3: Manage business relationships between partners, from RL cooperation initiation until termination.

Employees and their inherent work culture must also be managed. The activities developed in RL are performed mostly by human resources, and their failures are not easy to assess and model. So, to effectively run RL there must be the appropriate conditions to avoid human failures, conditioned by cultural differences, idiosyncratic factors (personality, motivation and responsibility) and suitable training for the RL roles. Hence, the main requirement that translates the presented need is:

FR_4: Manage human resources to perform RL activities.

At last, the fifth requisite concerns the information systems. Information systems provide the main data exchange infrastructure that will allow easing the access to the relevant data across organisations, regardless of if the activities are transactional or operational. As a consequence, the main FR for this matter is:

FR_5: Establish the information systems that provide the data required to run the RL process.

To fulfil the above FRs, the following DPs are proposed:

DP_1: The list of objectives (to implement RL), conflicts (of interests) and liabilities
DP_2: Description of a business process design, planning and coordination that fits the operational requirements of RL
DP_3: Description of the Interactive design of cooperation relationships, since initiation to termination
DP_4: Description of the work environment and training program that is suitable to the employee's characteristics
DP_5: Description of an IT solution suitable to support RL activities

Table 1 illustrates the design matrix of this level of the project.

Table 1. Design matrix for level 1.

	DP_1	DP_2	DP_3	DP_4	DP_5
FR_1	X	0	0	0	0
FR_2	X	X	0	0	0
FR_3	X	0	X	0	0
FR_4	X	0	0	X	0
FR_5	0	X	0	0	X

The present design is decoupled, requiring that the FRs are fulfilled in the specified order.

4.5 Definition of Level 2 FRs and DPs

The first FR fully describes the necessary detail to satisfy the strategic objectives of RL. Hence, this FR its not decomposed.

Other requirements must be fulfilled in order to achieve FR_2: clarify the business processes, the responsibility sharing definitions, the business process coordination, the business process visibility and the business process flexibility. Therefore, the sub-FRs for FR_2 will be:

$FR_{2.1}$: Establish clear RL collaborative business processes
$FR_{2.2}$: Define and ensure a correct responsibility assignment for RL implementation
$FR_{2.3}$: Coordinate RL processes between partners
$FR_{2.4}$: Ensure RL process visibility
$FR_{2.5}$: Ensure a required level of flexibility/adaptability in RL processes

To fulfil these requirements, the corresponding DPs are the following:

$DP_{2.1}$: Description of the reconciliation of the RL activities
$DP_{2.2}$: Identification (avoiding gaps) of the actors responsible for each activity
$DP_{2.3}$: Description of the model and of the material's optimization, process and information flows
$DP_{2.4}$: Definition of the way for communicating the process status between partners
$DP_{2.5}$: Description of how to reconfigure the processes to accommodate material flows oscillations

The relations between FRs and DPs for FR_2 are presented in Table 2.

Table 2. Design matrix for FR_2 (level 2).

	$DP_{2.1}$	$DP_{2.2}$	$DP_{2.3}$	$DP_{2.4}$	$DP_{2.5}$
$FR_{2.1}$	X	0	0	0	0
$FR_{2.2}$	X	X	0	0	0
$FR_{2.3}$	0	0	X	0	0
$FR_{2.4}$	X	X	X	X	0
$FR_{2.5}$	0	0	X	0	X

The design matrix for FR_2 is also decoupled, having only degrees of freedom for $FR_{2.1}$ and $FR_{2.3}$ that can be achieved independently.

FR_3 is related to the partnership monitoring, the establishment of cooperation contracts, the conflict management and the establishment of communication paths. Thus, the sub-FR's for this level are:

$FR_{3.1}$: Establish contract that spells conditions and liabilities and commits resources with responsibilities of RL
$FR_{3.2}$: Define communication paths for RL operations
$FR_{3.3}$: Monitor RL partnership
$FR_{3.4}$: Manage conflicts generated during RL cooperation

To satisfy these FRs, the following DPs were defined:

$DP_{3.1}$: A written contract must assign actors with the RL responsibilities
$DP_{3.2}$: The established communication paths that enable data exchange between complementary cross-organisational activities
$DP_{3.3}$: Description of the continuous assessment of partnership (during the production process and output evaluation)
$DP_{3.4}$: Description of the mechanisms to prevent and/or mitigate the occurrence of conflicts in RL activities

The relationships between the DPs and FRs for FR_3 are the following in the uncoupled design matrix (Table 3):

Table 3. Design matrix for FR_3 (level 2).

	$DP_{3.1}$	$DP_{3.2}$	$DP_{3.3}$	$DP_{3.4}$
$FR_{3.1}$	X	0	0	0
$FR_{3.2}$	0	X	0	0
$FR_{3.3}$	X	0	X	0
$FR_{3.4}$	X	X	X	X

The sub-FR's for FR_4 are:

$FR_{4.1}$: Avoid cultural and linguistic differences between employees performing RL
$FR_{4.2}$: Identify and mitigate interpersonal conflicts when implementing RL
$FR_{4.3}$: Ensure employees adequate training to perform RL

The corresponding DPs are the following:

$DP_{4.1}$: Description of the methods to mitigate the effect of cultural and linguistic differences
$DP_{4.2}$: Definition of individual roles and responsibility assignment that correspond to individual capabilities and work expectations
$DP_{4.3}$: Definition of the training programs for worker continuous revision of the learnt contents

The relationships between the DPs and FRs for FR_4 are the following (Table 4):

Table 4. Design matrix for FR_4 (level 2).

	$DP_{4.1}$	$DP_{4.2}$	$DP_{4.3}$
$FR_{4.1}$	X	0	0
$FR_{4.2}$	X	X	0
$FR_{4.3}$	0	0	X

To fulfil FR_4, the training of employees ($FR_{4.3}$) can be defined at any time, but to fulfil an efficient mitigation of interpersonal conflicts ($FR_{4.2}$), first one needs to address the cultural and linguistic issues ($FR_{4.1}$) of the employees.

Other conditions must be met in order to satisfy FR_5. For instance, the design of the IT interface must fit the needs of RL and simultaneously minimize the effect of human failure. Other concerns include security issues, data synchronization, interactions between databases and the IT application required to manage RL. Hence, the sub-FR's for this category are:

$FR_{5.1}$: Design the IT application for RL information needs
$FR_{5.2}$: Design the IT interface for RL operations
$FR_{5.3}$: Design information systems that are able to exchange RL data
$FR_{5.4}$: Establish the databases and/or the database interfaces that allow the data flows related to RL

To achieve these requirements, the following DPs are proposed:

$DP_{5.1}$: Description of the adopted IT to RL functional areas
$DP_{5.2}$: Description of the IT interfaces that replace manual interfaces in order to reduce human dependency
$DP_{5.3}$: Description of the data synchronization required to achieve RL
$DP_{5.4}$: Selected common data resources

The relationships between this set of FRs and DPs are presented in Table 5.

Table 5. Design matrix for FR_5 (level 2).

	$DP_{5.1}$	$DP_{5.2}$	$DP_{5.3}$	$DP_{5.4}$
$FR_{5.1}$	X	0	0	0
$FR_{5.2}$	X	X	0	0
$FR_{5.3}$	X	0	X	0
$FR_{5.4}$	0	0	X	X

This design matrix is uncoupled, and requires that the FRs are achieved in the specified order.

Figures 3 and 4 summarize the descriptions above. Figure 3 depicts the system architecture, while Figure 4 contains the corresponding complete design matrix.

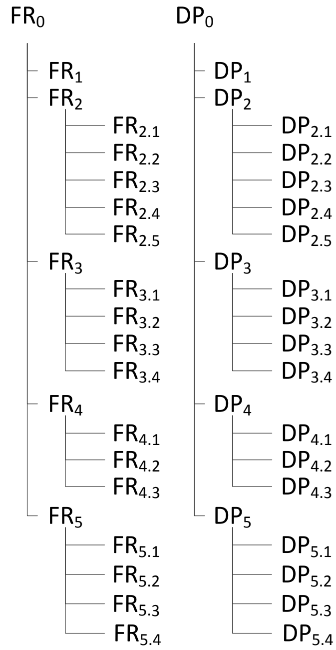

Figure 3. The RL system architecture.

	DP1	DP2	DP3	DP4	DP5	DP2.1	DP2.2	DP2.3	DP2.4	DP2.5	DP3.1	DP3.2	DP3.3	DP3.4	DP4.1	DP4.2	DP4.3	DP5.1	DP5.2	DP5.3	DP5.4
FR1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR3	X	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR4	X	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR5	0	X	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2.1	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2.2	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2.3	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2.4	0	0	0	0	0	X	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0
FR2.5	0	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	0	0	0	0	0
FR3.1	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0
FR3.2	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0
FR3.3	0	0	0	0	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	0	0
FR3.4	0	0	0	0	0	0	0	0	0	0	X	X	X	X	0	0	0	0	0	0	0
FR4.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0
FR4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0
FR4.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0
FR5.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0
FR5.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0
FR5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	X	0
FR5.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X

Figure 4. Complete design matrix of self-supported reverse logistics between focal firm and 1st tier supplier.

5 CONCLUSIONS AND FUTURE WORK

This article proposes a design solution to establish a reverse logistics (RL) relationship between a focal firm and a 1st tier supplier, in which the focal firm manages and coordinates the activities of RL.

The application of the Axiomatic Design allowed us to systematize the reverse logistics definitions, considering the business interoperability parameters, making it possible to decide in which sequence the activities must be fulfilled. For instance, in the management of external relationships during cooperation (FR_3), first one needs to formalize a contract ($FR_{3.1}$). Next, one should define the communications paths ($FR_{3.2}$) that allow the partnership monitoring ($FR_{3.3}$). This will allow us to manage the conflicts generated during RL cooperation ($FR_{3.4}$). However, there is no precedence over $FR_{3.2}$, a fact that allows us to perform this task before $FR_{3.1}$.

Although it was possible to demonstrate the potential of Axiomatic Design to describe how to achieve an interoperable reverse logistics relationship between a supplier and a focal firm that manages the RL operations, some difficulties arise from this method (for example, the decomposition of the reverse logistics design aspects into interoperability requirements). There are several approaches to implement reverse logistics, in both the literature and the practice. All those approaches require an in depth knowledge about the models that rule the green supply management (for instance transaction cost economics and resource-based view).

Future work will focus on detailing the present model and developing other scenarios that could fit the presented situation, namely, the collaborative RL model (CS_2) and the third-party RL model (CS_3). These achievements will make it possible to apply the Information Axiom, allowing us to determine which design fits best to the needs of the focal firm.

Research will also be conducted in the field of computer simulation and business process modelling, and will address the testing and validation of the design. Also, the effect of interoperability variables in the RL metrics will be studied using the response surface methodology and design of experiments.

6 ACKNOWLEDGEMENTS

The authors would like to thank Fundação para a Ciência e Tecnologia for providing a research grant to Pedro Espadinha da Cruz through the project PTDC/EME-GIN/115617/2009.

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