

Designing Eco-Effective Reverse Logistics Networks

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Abstract. Reverse Logistics Networks (RLNs) have grown in importance after return policies became compulsory. Lately, questions have been raised whether they are as helpful to the environment as possible. Efforts have been conducted to optimize RLNs in terms of their *eco-efficiency*, minimizing costs and emissions; still, results are not advancing with the necessary speed. Alternatively, the *eco-effectiveness* (“doing the right thing” for the environment) approach emerges, promoting a supportive relationship, balancing environment and economy. This research aims to model the design (or redesign) process of eco-effective RLNs. There are numerous ecodesign tools focusing on product or service design, but an eco-effective design process conceived specifically for logistics network design purposes has yet to be delivered. Research was carried out using the Design Science Research Methodology and an exemplification was outlined to demonstrate how the process unrolls. The model was conceived using a combination of the TRIZ method, Upcycling and Industrial Symbiosis. Eco-efficiency of these networks was not evaluated. The proposed design process model will help the conception of more innovative, eco-effective logistics networks.

Keywords. Upcycle, Reverse Logistics Network Design, Industrial Ecology, TRIZ, Material Flow.

Introduction

Much has been discussed about the role of companies and their manufacturing processes in the development of a truly sustainable world. Measures are being taken by many entities, whether governmental, private, worldwide or regional, but there are still many questions to be answered, with the perception that the approach against environmental deterioration must change [1].

Huge challenges for Sustainable Manufacturing remain in one of its business processes: the **Reverse Logistics** (also called Closed-Loop Supply Chain), which concerns the backward flow for every manufacturing element (e.g. packaging, raw materials) [2]. After sustainable concerns reached industries in general, Reverse Logistics has grown importance by helping decrease environmental impacts. Now a new question emerges: are they being as helpful to the environment as they could be?

Trying to answer this question, major efforts in Closed-Loop Supply Chain (CLSC) have been spent to assess a Reverse Logistics Network (RLN) in terms of its **eco-efficiency** – the ability to deliver the least environmental impact while keeping

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costs as low as possible –, through the development of stochastic and deterministic models that simulate environmental and economic performance using optimization techniques (DEA, Pareto Optimality, MILP, MINLP, and others) [3]–[10].

These researches have contributed significantly to the improvement of RLNs eco-efficiency, but such efforts – considered “oriented for business” by [1]– are not being capable to avoid the increase of environmental burdens: our society is still moving towards a population collapse in 2030 – only fourteen years from now [11]. Bolder initiatives are needed in order to avoid, or at least delay, these outcomes from becoming reality.

In this scenario, the **Upcycling** appears as a concept that is a more effective – or **eco-effective** – design approach, promoting a supportive relationship between environment and economy [12], by leveling their importance in what is considered a **system** approach, accounting for interactions between them while seeking the best performance in both dimensions. After this approach, RLNs now have to be designed (or redesigned, if it is already in place) to Upcycle the environment, what can be achieved by “waste equals food” symbiosis among companies .

In this paper, Design and Redesign will be combined in the sole term (re)design. This research aims to model the (re)design process of Eco-effective Reverse Logistics Networks. The model, represented by a process flowchart, is the artifact that aims to help addressing eco-effective solutions to RLNs. The (re)design flowchart also describes activities, information needed and decisions one has to make while designing eco-effective RLNs. Finally, a short exemplification is proposed to demonstrate its use.

The article is organized starting with a literature review in the Section 1. Section 2 brings in the methodology used to create the flowchart. Section 3 contains the resulting flowchart. Section 4 presents the exemplification of the Poultry Industry and in Section 5, final considerations over the research and its limitations are detailed.

1. Theoretical Background

In source [12], the authors have made an effort to understand main researches in sustainable design and manufacturing domain, where they categorized many initiatives such as Green Supply Chain Management and Industrial Ecology. Both fields of study are somehow related, and, in this section, each concept used for the artifact development is further described.

1.1 Reverse Logistics Design

According to the European Group on Reverse Logistics, Reverse Logistics is “the process of planning, implementing and controlling backward flows of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal” [2]. A typical RLN structure is presented in [Figure 1](#)[13]. It shows the forward logistics - the classic logistics where finished products are delivered to the market. The Reverse Logistics features the convergent network that takes the end-of-life products back to the recovery facilities, or distribution points.

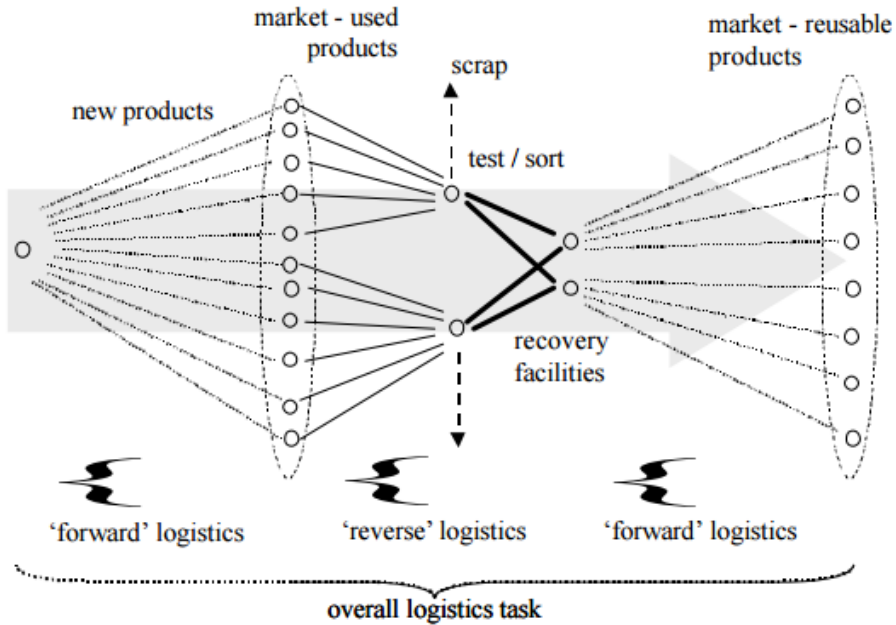


Figure 1. Reverse Logistics Network Structure (Fleischmann, 2001).

The eco-effectiveness principles are subject for the next topic.

1.2 Upcycle: being eco-effective

The Upcycle is described in [14] and it represents a change in the design paradigm. Through rethinking design intentions, it is possible to bring benefits to the environment, taking advantage from the undesired outcomes of production processes as stated in their main principle: “waste equals food”. Some major points defined as drivers for an eco-effective design are worth describing:

1. **We don't have an energy problem. We have a materials-in-the-wrong place problem.** A designer must not consider how much emission his product is sending in first place: he must ponder if his emissions are going to the right place;
2. **Get “out of sight” out of mind.** Society is used to think about what they put in garbage cans and toilets as worthless material. The authors claim that, instead, these are recipes for nutrients that are probably missing for many other productive activities under development in our communities;
3. **Always be asking on what's next.** Every waste or material that is left behind can be asked endlessly for “what is the next process that it will serve as ‘food?’” It does not means that one can use harmful raw materials such as toxic products;
4. **Add good on top of subtracting bad.** The authors state that recognition must be given to everyone who's performing actions to improve the environment;
5. **Gaze at the world around you... Then Begin.** Before designing a solution, one must observe the context and profit from local features;

A discipline that is taking eco-effective measures like “waste equals food” is the Industrial Ecology, which, through Industrial Symbiosis, is promoting industrial relations where waste from one industry is raw material for another productive process, covered in the next section.

1.3 Industrial Ecology

Industrial Ecology is defined as “the exchange of materials between different industrial sectors where the 'waste' output of one industry becomes the 'feedstock' of another.” [15]. Material flows are exchanged among companies geographically close together, considering waste as inputs.

In order to enable IE networks, collaboration is fundamental. To support collaboration options, the C4S (Collaboration for Sustainability) tool [16], developed in the SCALE (Step Change in Agri-Food Logistics Eco-Systems) project, was selected. It defines procedures and the activities sequence to put in place new supply partnerships. The process is divided in three phases: preparation, C4S workshop and implementation.

Industrial Ecology is about defining solutions that decreases environmental impacts. In order to generate the upcycle effect, creative, eco-effective material flows have to be defined. Creative design is achieved through methodologies like TRIZ, used in this research and described in the next topic.

1.4 Designing Solutions: TRIZ

TRIZ is an acronym of the Russian "theory of the resolution of invention-related tasks" (in English, TIPS, Theory of Inventive Problem-Solving). It is defined as a “problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature” [17], based on the fact that (i) problems and solutions are often repeated throughout industries and researches and (ii), evolution patterns and creative innovations under development take advantage of effects from researches of other areas [18]. TRIZ is based on the fundamental concepts of Ideality (systems improvement), Contradiction (evolution involves resolution of conflicts), Resources (surroundings can be used to solve the problem), systematization of the problem solving and use of functional diagrams, to represent a problem [19]

Figure 2 represents the strategy of the TRIZ methodology. First it is needed to identify the problem and match it to a general TRIZ problem. If this has been done correctly, a TRIZ general solution (among what is called “TRIZ 40 principles”) is found and brought to the specific problem context, represented in the bottom right square. This last analogy will transform the general solution into a specific solution for the problem under investigation. Blue arrows represent analytic activities and the red arrow represents thinking by analogy.

TRIZ main concern is about the conceptual solution of a given problem, whether it contains a contradiction or not [19]. TRIZ general directives determine that, at the highest level, production can be achieved with no waste at 100% efficiency, which are in line with Eco-effectiveness principles. Next, methodological procedures will be explained.

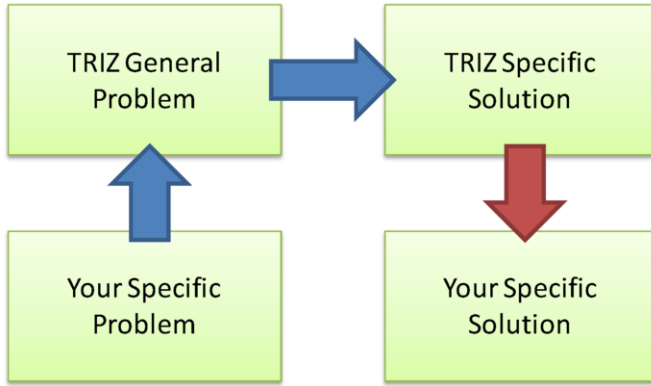


Figure 2. TRIZ Methodology (Barry, Domb and Slocum, 2010).

2. Methodology

This research aims to propose a solution for the problem of Eco-effective Logistics Networks Design. This solution is approached as an artifact and, to develop it, we take advantage of the Design Science Research Methodology (DSRM). [20] present a structured framework of the principles, practices and procedures needed in order to develop a research under the domain of the Design Science. Figure 3 represents the framework, which is composed by 6 phases: Problem Identification and Motivation, Definition of the objectives for a solution, Design and Development, Demonstration, Evaluation and Communication.

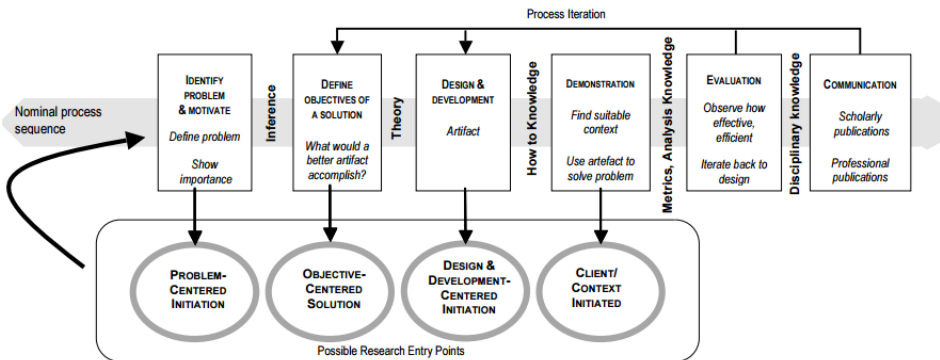


Figure 3. The DSRM structured framework (Peppers et al., 2007).

The first two phases have already been described in section 1: the problem has been delimited and the artifact proposed to solve the problem is a process model. This section is about the Design & Development phase of this model; section 4 will look at Demonstration activities. The Evaluation phase is yet to be performed in future research. Communication will be performed in conferences. Next section will go through the Design and Development phase.

2.1 *Artifact Design and Development*

First, a representation model was selected after the nature of the artifact being proposed, in a business process perspective of a “chains of events, activities and decisions that ultimately add value to the organization and its customers.” [21]. Business Process Modeling (BPM) was used to create a process flowchart that represents the proposed artifact.

It also necessary to clearly define what an “eco-effective RLN” should be. The Reverse Logistics definition concerns backwards material **flows**: in order to obtain an eco-effective RLN, they must be reviewed. To upcycle the environment, the least processing needed in order to convert waste into inputs, the better. Industrial Ecology is used as a benchmark for upcycling material flow solutions.

As there are many IE initiatives contained in an extensive literature, the design process would benefit from gathering these experiences after the problem has been identified. This information could be grouped in a benchmark database to support the designer during the material flow (re)design process, where he/she could identify possible symbiosis relations to be proposed. In the exceptional cases he/she could not find a solution in the database, the designer will need to create an eco-effective material flow solution. This activity could be performed by means of TRIZ methodology, following its premises and orientations.

After the selection of a solution from the database (or the creation of a new solution), the design process has to look for its feasibility and implementation. C4S methodology helps gathering companies to discuss and implement such new materials and logistics flows. If these new agreements fail to be implemented, the designer will require an alternative path to follow.

3. Findings – the (re)design process flowchart

The RLN Design Process Flowchart is represented in [Figure 4](#), containing events, activities and decisions that take place during the process in order to (re)design an eco-effective Reverse Logistics Network.

The process begins with the activity of mapping the current material flow, where a diagnostic is performed and every material flow – from incoming until final product expedition – is identified. Normally, the designer will have to go through all process stages and facilities to understand the material flow and resources used, e.g. transportation and final destination.

After material flow mapping, the designer can go through the Industrial Ecology Database to search for a similar solution to his/her problem. If a solution can be found in the database, the designer can go forward to the next step: implementation. If not, next step will be to create a solution through a TRIZ-like innovation process.

Following TRIZ methodology, one will go through the TRIZ database and establish potential “waste equals food” relations: starting from the material, he/she must define a solution – what could be done with it? After TRIZ principles, the designer must address these solutions after understanding features from that material like chemical composition, weight and capacity to generate energy.

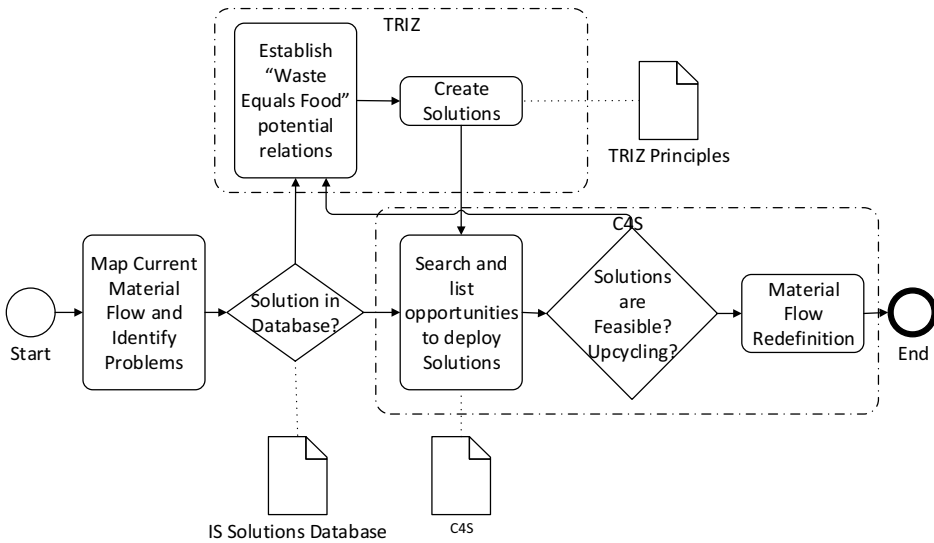


Figure 4. Reverse Logistics Network Design Flowchart.

After completing this activity, he/she can look for opportunities to deploy these solutions, taking advantage of C4S. Locally, the designer can search for entities (e.g. companies, universities) that could receive any of the materials under analysis. When the workshop has finished, one can realize feasible possibilities and evaluate if solutions are indeed eco-effective. If not, the designer will have to restart the TRIZ process and create other solutions for the utilization of the material.

4. Demonstration Example: Poultry Industry

As a demonstration of the above flowchart (according to DSRM’s Activity 4), a designer that works for a Poultry Farm that needs to implement Reverse Logistics will map material flows and arrives at results similar to those found in [22]. In this case, searching the database (presented in Table 1, based in [22]), he/she will find eco-effective solutions that could be implemented as a solution. Then, companies that uses the listed materials as inputs for their processes can be mapped.

Table 1. Eco-effective Material Flow Database.

"Waste equals Food" Database				
No.	"Waste"	"Food" for	Description	Source
1	Unbroken Rejected Egg	Biscuits and Cakes	Bakery Industry	Shamsuddoha (2011)
2	Broken Rejected Egg	Fish	Fish Industry	
3	Processed Feathers	Bed and Pillow	-	
4	Chicken Paste	Fish	Fish Industry	
		Fertilizer	Crop Industry	
5	Poultry litter	Bio-gas	Energy Generation	
		Charcoal	Energy Generation	

Taking the poultry litter waste as an example, solutions were found in the database: therefore, there was no need to go through steps 4 and 5. The poultry litter can be used in the production of three different materials: fertilizer (by crop industry), bio-gas and charcoal for energy generation. With these three possible solutions, the

designer can locally search for industries of such industrial activities. Assuming that two fertilizer companies and one Bio-gas plant have been located – see Figure 5 –, the designer contacts these three companies to propose symbiosis relations with them.

Figure 5 shows that the bio-gas plant is a lot further than fertilizer companies, so it presents a major difficulty for symbiosis at first evaluation. Company “B” stands as the most proximate potential customer for receiving the poultry litter. Fertilizer company “A” has a commercial relation in place with the Poultry Farm, which includes logistics operations with the farm: a truck goes from the fertilizer company “A” loaded with goods and returns empty – this established roundtrip must be considered in the evaluation. Selling to company “B” would require setting a new logistics operation. The designer must compare both alternatives in terms of environmental benefits in order to choose the most eco-effective, using the evaluation model proposed in the next section.

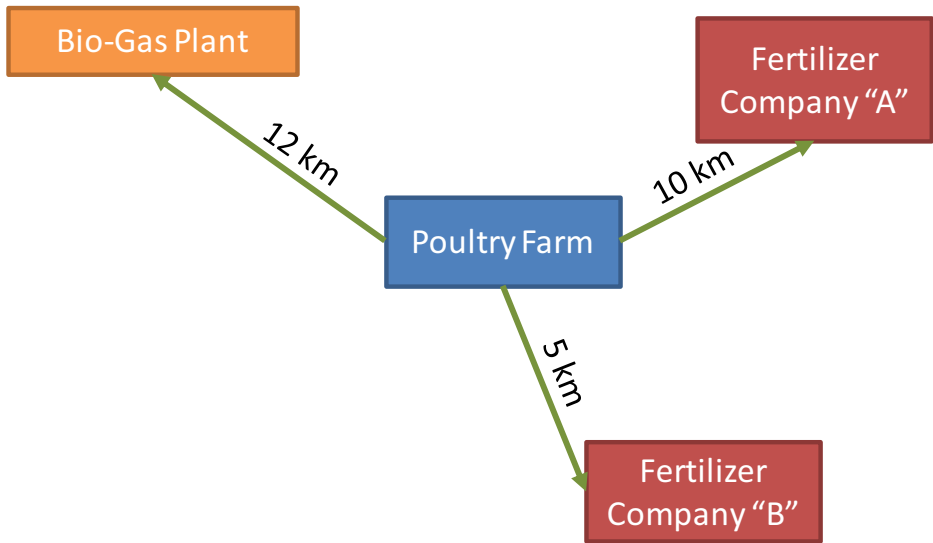


Figure 5. Diagram representing distances from potential symbiosis relations.

4.1 Evaluation Proposal – DSRM Activity 5

Figure 6 describes a model proposal for the direct comparison between material flows. Poultry litter flow from Poultry Farm to current destination presents an environmental impact that can be quantified considering the system in the X box. New potential material flows from the Poultry farm to Company “B” (represented by α and α') can be quantified in terms of their environmental impacts – box for systems Y and Y' . New flows could, sometimes, include transformation processes to adapt this wasted material to be consumed – this is represented in system Y' .

To identify quantitatively the benefit achieved by the adoption of a new material flow strategy, the previous impact is subtracted from the new environmental impact and a benefit value is found, represented in Equation 1. The degree of environmental benefit (ΔB) can then be quantified. If the result returns a negative value, there is an increase on the environmental impact.

$$\Delta B_i = Y_i - X \tag{1}$$

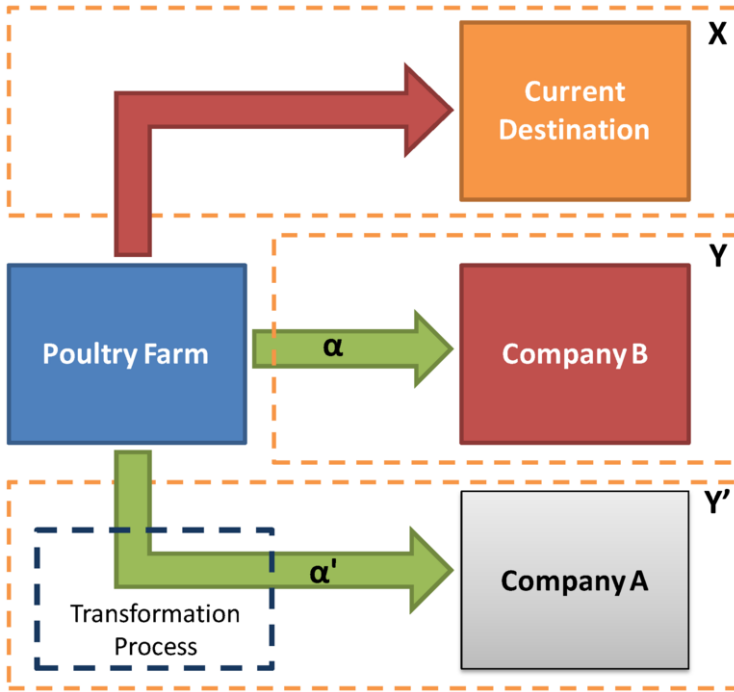


Figure 6. Conceptual model for the evaluation of the new material flow eco-effectiveness.

5. Final Considerations

This paper attempts to define a process flowchart to systematize the design process of Reverse Logistics Networks. It is stated that an eco-effective RLN is the one where material flows are upcycling the environment through “waste equals food” relationships. In order to allow that, a solutions database must be developed using benchmarks such as Industrial Ecology and Industrial Symbiosis.

TRIZ was chosen as the innovation methodology in case there were no previous solution for a specific material flow in the database. Upcycling principles were formalized as guidance to the innovation process. The rest of the process concerns finding and seizing opportunities to deploy solutions and implementing the new material flows.

Under the present study, Reverse Logistics Networks are limited to Client and Supplier and their material flow relations. Aspects of Transportation and routes were not addressed in this research. There was no evaluation of the eco-efficiency of the eco-effective solutions: this is future research that can be performed. Another limitation is that the quantity of waste produced has to be compared with the raw material quantity to be replaced. This research assumed that production volumes are similar. If waste volumes are lower, only a partial benefit is achieved by the symbiosis. If waste volume is higher, more than one symbiosis relation can be established.

Evaluation phase also needs to be better detailed, with indicators and procedures based in Lifecycle Assessment techniques, to support designers to better understand, make decisions and explain benefits achieved through to material flow redefinition. Although it will be very rarely used – as there are “food for” destinations for practically every type of waste, complementation in the TRIZ process is also needed, to define the proper concepts, ideation techniques and tools among the many available inside the TRIZ methodology. The flowchart needs to be reviewed to better represent the activities for the Reverse Logistics Network definition and singularities from Industrial Symbiosis initiatives.

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