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Environmental Issues in Supply Chain Management

New Trends and Applications

Springer

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Preface
On the Way to Environmental Friendly Supply Chain Management

Traditionally, supply chain management is defined as design, planning, and control of flow of goods among a number of independent entities from sourcing base to the final consumers. For the last 20 years, environmental issues of supply chain management have gained a growing concern among academia and practitioners. First, this was because governments imposed new regulations for environment protection in a number of countries around the world and then researchers have included these new constraints and objective functions in their models to represent better the new reality. The second reason is because companies have faced the need to seek for new ways of costs reduction and appropriate products returns management. The effort to improve supply chains using environmental friendly management approaches results in manufacturing performance improvements by developing new ways to manage product quality, quantity, and production system flexibility by collaborating with suppliers, dealers, and consumers. In order to do this, companies have to fix their common environmental objectives, sharing technical information about products, planning and processes, or starting common programs to reduce adverse impacts over the environment.

The aim of this monograph is to present the emerging environmental issues in the organization and management of supply chains. The scope of the book takes into consideration how the emerging environmental regulation might be transformed into business practices. Therefore, authors present, in individual chapters, innovative approach to eco-friendly organization and coordination of logistics processes and supply chain configuration.

In this monograph the emphasis is placed on three main areas:

1. Environment and supply chain operations—the objective of this area is to present a general framework to understand how supply chain operations can be improved when environmental issues are taken into account;
2. Reverse logistics—example of electronic and electric equipments waste management; this area is devoted to a broad field of reverse logistics. The chapters

included in this area are good examples of supply chain best practices in equipment waste recovery and management;
3. Sustainability issues—sector specific solutions. The last part presents good examples of both quantitative and qualitative studies where the reader will see the application of environmental management to real cases.

The aim of the first chapter is to present the main performance criteria, social, and environmental, which are used for finding the optimum of the enterprise and its supply chain using GRAI approach. This criterion is used as one way for helping enterprises to improve themselves for being competitive faced with the new economic context to model.

The next chapter aims to identify the enablers to sustainability in the supply chains and their mutual relationships. The author proposes the classification of the enablers to explain better their influence on the supply chain management in sustainable manner.

In the subsequent chapter the authors propose a conceptual process framework of problems occurring in organizations of transport processes within distribution systems. This solution is tested in the apparel industry, which is characterized by a high demand for transport services.

Chapter 4 contains analyses of e-markets for waste management in Poland. The authors evaluate a number of existing information platform to present their advantages and weaknesses. It is an interesting study of how information technologies can contribute to further development of the reverse logistics.

The problems of reverse logistics organization and optimization are described in the five subsequent chapters. Emphasis is placed on the electronic and electric equipment waste management (WEEE). The WEEE is the fastest growing waste group among all. It is mainly because of very short life cycle, growing demand, and decreasing cost of products. The analysts estimate that the number of PCs is growing about 12 % annually. At that pace, it will reach two billion units by early 2014. Also, the number of mobiles and household appliances is growing very rapidly. As a result the volume of e-waste is increasing three times quicker that other waste categories. According to the WEEE Forum[1] the European Union itself is generating over eight million tons of e-waste per annum.

The authors in Chap. 5 discuss the problems of complex relations between reverse supply chain participants. Companies have problems to stimulate the time and quantity of returns. Due to dynamic changes in the recovery network planning many weeks in advance is difficult because forecasts quickly become outdated. The authors propose a model to overcome these difficulties.

The next chapter focuses on optimizing the recycling process of electronic appliances. A methodology that takes into account technical, economic, legal, and environmental issues is proposed by the authors.

[1] www.weeeforum.org

In Chap. 7 the authors present a decision support platform for the strategic and operational planning in reverse logistics applied to a multi-stage collection network of electronic and electric equipment. This chapter concerns a holistic approach on reverse logistics including a hierarchical process of decision making on the allocation of customers and vehicle routing with different transportation modes.

The problem of vehicle routing is also addressed in the subsequent chapter, where the authors present how the European Union Directive 2002/96/EC on Waste of Electrical and Electronic Equipments (WEEE) might be transformed into vehicle routing practices. The integer programming is applied to solve the problems in the recovery networks.

The problems of reverse logistics for WEEE are concluded by the chapter on the impact of the emerging environmental regulation of batteries on the Spanish collection and recovery system. The authors identify the main problems regarding this system as well as propose the improvements to the current reverse logistics system.

The last part of the book presents the problems and applications typical for selected industries. The idea of sustainable development emphasizes the rationalization of the demand for resources and services.

Chapter 10 presents advanced techniques applied by the authors for the detection and quantification of biomass. On the basis of analysis of the previous results, logistics models are developed for determining the optimal collection points, transportation routes, and location of the processing industries.

In the next chapter focus is placed on the food industry. The authors conduct analyses of the environmental impact of mass and energy flows when the product moves from “cradle to grave” and the product life cycle to predict the operation and use of energy associated with the production. They also propose some improvements related to forward and reverse logistics operations in order to increase the energy efficiency of the company.

Sustainability issues in the tourism industry are described in the subsequent chapter. A detailed description of the sustainable tourism model at Vall de Núria is given. The authors explain how a friendly tourist destination is achieved by application of environmental awareness to regional development.

The transport sector is crucial for sustainable development. The development of the railway infrastructure might significantly contribute to the the reduction of congestion and CO_2 emissions. The authors in this chapter present how new business models might enable railway companies to improve their services, reduce operating costs, and minimize the environmental impact of transport operations. They provide an initial overview of business model renewals in the European railway sector and their environmental impactions.

The final chapter presents the influence of e-commerce development on urban logistics. The authors identify the impact which e-groceries have on distribution processes. They analyze ways to better use the last mile delivery vehicles in order to lower greenhouse gases emission in urban areas.

This monograph provides a broad scope of the current issues important for the development of the environmentally friendly supply chain management. It is a composition of theoretical trends and practical applications. The advantage of this book is the presentation of practical applications from a number of different countries around Europe.

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Contents

Part I
Environment and Supply Chain Operations

Using Environmental Demands to Improve Supply Chain Performance

Paul Eric Dossou and Philip Mitchell

Abstract This chapter presents GRAIMOD a tool for supporting GRAI Methodology. This tool is used for managing Enterprise and particularly Supply Chain performance improvements. In addition to the main performance criteria, social, societal and environmental dimensions will be used for finding the optimum of the enterprise. A detailed example will be given for illustration. The originality of this chapter is the definition of carbon footprint (management) as a new performance criterion. The future supply chain has to integrate this new dimension. The example presented also studies the possibility of using the tramway for transporting raw materials and products in a city.

Keywords Carbon footprint · Performance criteria · Environmental · Social and societal dimensions · Enterprise modeling · Supply chain optimization

1 Introduction

As a result of the gloomy economic climate in Europe brought about by the ongoing crisis affecting all enterprises (particularly SMEs) in France, the French government has recently decided to create different poles of innovation and research associated to the activities of enterprises. The objective is to propose new ideas for helping these enterprises to be more efficient and able to resist the threat to their existence from globalisation.

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One of the difficulties of these enterprises is that they find it difficult to penetrate the European market and export their products. This is due to many reasons the main one being global manufacturing costs. In fact with globalisation it is less expensive to produce in China or India rather than in France or Germany. There are also other reasons which are subjective reasons corresponding to quality of the products, brand awareness, the desire to export and product promotion.

In this context some research has been carried out for integrating the environmental dimension into the supply chain of the enterprises of the West of France.

In an enterprise supply chain, carbon management could be considered as a new criterion in addition to quality, cost and delivery date. How to redefine the optimum of the enterprise by integrating the environmental dimension with efficiency? For instance, GRAIQUAL a module of GRAIMOD is designed to implement, manage and improve quality in enterprises. It contains norms and certifications. Quality could be improved in each part of the supply chain by distinguishing process, products and supplier quality and quality management. The reduction of cost and lead time simultaneously with quality improvement is also achieved. Moreover the global reduction of carbon in the supply chain allows to obtain a green and sustainable supply chain adapted to the future. In fact, it is important for enterprises to prepare themselves for the end of the current crisis in order to be really efficient in future circumstances. So they have to take into account the changes in our world and anticipate them by introducing in the management of their supply chain the social, societal or environmental dimensions.

A zoom on the dispatch management (delivery of products to their customers and organisation of the dispatch process) and on the procurement management enables enterprises to notice that nowadays the main means of transport for them is the use of trucks. How to integrate the other types of transport in order to reduce carbon? The main difficulty is the cost of carbon management. So it is important to show enterprises that even if the reduction of carbon and the respect and the use of environmental demands and norms have a cost, this could be optimised by the enterprise and used as new marketing strategy for obtaining new markets and being in coherence with the new expectations of our society. It goes without saying that globalisation means more distance, more competition, more customers, more organisation and the enterprises (particularly the SMEs) have to make the effort in order to have clear visibility and to be more efficient than the other companies.

For instance, a city like Nantes has a tramway network for transporting passengers. In the city of Nantes and around there are a lot of enterprises needing to manage their procurement on a daily basis. They also have to manage the delivery to their customers. At present, they use trucks and shuttles for delivering customers and acquiring procurement. The objective is to study how to organise the use of the existing tramway railway for transporting raw materials and customer goods. The use of the tramway would allow to reduce carbon in the city thus for each enterprise.

This chapter presents the concepts associated to the tool but also a detailed example to illustrate them. A study is also done for showing the feasibility of combining the tramway for passengers with the transport of goods.

2 GRAIMOD: A Tool For Supporting GRAI Methodology

GRAI Methodology is one of the three main methodologies (with PERA and CIMOSA) used for modelling enterprises. GRAIMOD is software being developed for supporting this methodology in the improvement of enterprise performance.

2.1 GRAI Methodology

GRAI Methodology is used for analyzing and designing enterprises (Chen et al. 2008). GRAI approach is composed of four phases:

- An initialization phase to start the study,
- A modeling phase where the existing system is described,
- An analysis phase to detect the inconsistencies of the studied system,
- And a design phase during which the inconsistencies detected are corrected, and a new system proposed.

The GRAI methodological tree is composed of five domains as clearly shown in Fig. 1 (Doumeingts and Ducq 1999). Scientific concepts are defined for each domain in order to model, analyze, and improve enterprises. For instance GRAIPROGI and GIMPLANT are defined for the computer solution choice and Implementation/technique/organizational domain. These concepts are essentially used to choose and implement a computer tool (Supply Chain management and ERP) which meets the real market needs (globalization, relocation, capacity to be proactive, cost optimization, lead time, quality, flexibility, etc.…). For example, the GRAIPROGI approach is completely integrated in GRAI methodology approach. The 'AS IS' models describe the existing system. The components of the system are already known, described and formalized. It is therefore possible to easily understand the system and pinpoint the strengths and weaknesses.

The 'TO BE' corresponds to models for the future originating from the design phase of the GIM (GRAI Integrated Methodology) approach. The 'AS IS' and 'TO BE' models (Fig. 2) have the same structures (physical, decisional, informational, functional and process models); The 'TO BE' model is therefore the result of a combination of the ambitions of the enterprise, the constraints of the existing system and the realistic aspirations taking into consideration the economic environment (Dossou and Mitchell 2009).

Then an action plan is defined. The next stage is the execution of the action plan over the short, medium and long terms. At the same time the 'TO BE' models are transformed into the specifications needed to obtain the road book on the one hand to reorganize the enterprise and in order to improve performance and on the other hand to select the most suitable tool.

From the specifications we deduce:

The global architecture contains the computer features desired (client/server architecture, data base SQL server…). This architecture can lead to the development

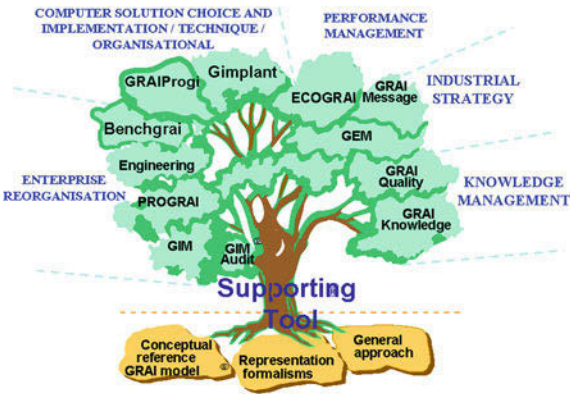


Fig. 1 The GRAI Methodology tree

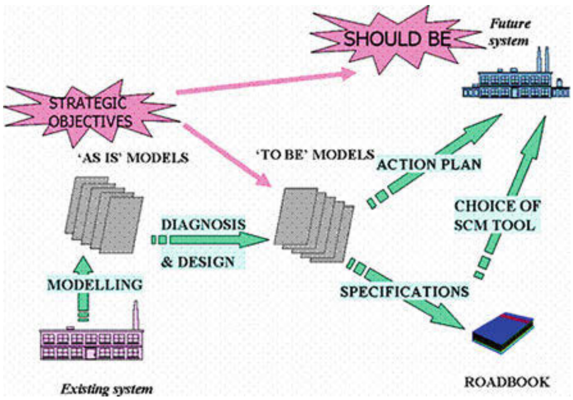


Fig. 2 Use of enterprise modeling for choosing an SCM tool

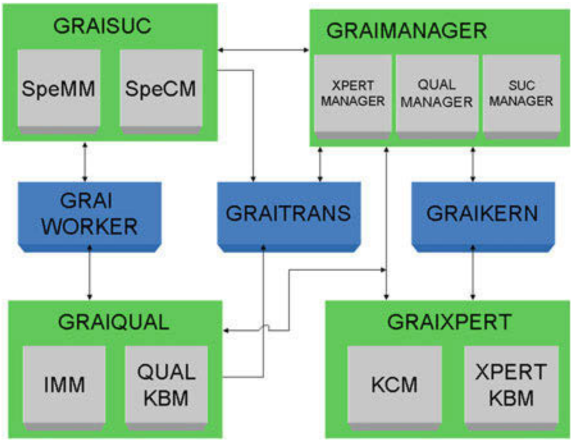
of SCM software. Most frequently, however, enterprises normally choose already existing software. An action plan determines the evolution of the project with the choice and implementation of software. The specifications should also consider social, technical and human factors.

For supporting the concepts presented in the GRAI methodological tree different software tools were developed. GRAIMOD is the new one being developed by ICAM Engineer School for covering the five domains and proposing concrete solution for improving enterprise supply chains. The following chapters present the architecture of this tool and how it could be used for improving sustainable supply chains.

2.2 Architecture of GRAIMOD

In Fig. 3 the integrated general architecture of the new tool GRAIMOD is presented (Dossou and Pawlewski 2010). We can notice that this tool contains four modules working around a kernel (GRAIKERN). It corresponds exactly to the

Fig. 3 Architecture of GRAIMOD



actual level of design. The techniques used for developing the tool have to integrate a progressive addition of other modules in order to be compatible with the GRAI methodological tree.

GRAIKERN is a graphic editor used for representing the different models associated to GRAI methodology. It is an interface between the different modules. GRAIMANAGER is a management module used for organising the different interactions between the modules of GRAIMOD. It controls and manages the system's interactions with the users. It presents the users with appropriate questions and choices together with the necessary information about the characteristic of the enterprise studied. It also manages the rules classified according to a typology of production systems. Its main tasks are the modification, suppression or selection of the applicable rules in a given context. It is also used for the loading and the saving of rule files. Finally, it controls the design process, different actions of the sub-modules and their interactions. GRAIWORKER is the work base elaborated for managing, modifying and capitalising knowledge about the case studied. GRAITRANS is a Transfer Interface used for putting the new case in GRAIXPERT in order to improve its Cases Base. The reference model elaborated for each enterprise domain will be improved by the acquisition of this new model in GRAIXPERT.

2.2.1 GRAIXPERT

GRAIXPERT is a hybrid expert system (Russell and Norvig 1995; Xia et al. 1995; Yahia et al. 2000) for managing the analysis of the existing system and proposing a new system. We define knowledge as the process which transforms the whole set of known information Ci (stable state) into another Ci + 1. Knowledge Ci+1 can be therefore defined as a sum of disjointed information or as a progressive improvement of the whole—C1 implying a restructuring of already acquired information. How does a child obtain understanding of the world around him? He integrates the new element with his already acquired knowledge and he structures his learning by employing actively what he has just experienced.

Both cases correspond to a refinement of knowledge by the addition of distinct (new) knowledge or the improvement of existing knowledge (Colin 2002). We use this concept to define three modes of knowledge representation:

- The reference models show the standard for a given sector of activity. They allow to define an ideal for each sector of activity, which can be used as a reference in the elaboration of the future model (TO BE).
- The cases studied are capitalized in order to enrich the knowledge capitalization module of GRAIXPERT with the objective being to improve the use of CBR (Case Based Reasoning) (Aamodt 1994; Arezoo et al. 2000; Brown and Chandrasekaran 1985).
- The rules are used throughout the different phases of the operation of GRAI methodology. Not only do they serve to elaborate the modules concerning the existing situation of the enterprise (AS IS) but also to detect the malfunctions of the enterprise and establish its strengths and weaknesses and finally during the design phase of the future system (TO BE).

GRAIXPERT is composed of two sub-modules in interaction with GRAIKERN: the Knowledge Capitalization (KCM) and the Knowledge Based System (XPERTKBM) (Dossou and Pawlewski 2010).

The Knowledge based system contains a rule base used for analyzing the different models in order to detect inconsistencies and propose corrections. A dictionary is used to translate the user's expressions into standard expressions provided by the GRAI methodology.

The knowledge capitalization process needs some aptitudes to manage different know-how and points of view. It must integrate this knowledge in an accessible, usable and maintainable form. It offers an expertise model based on the knowledge of the experts but also on the previously realized studies. The capitalization module is composed of an acquisition module for integrating other expert knowledge, a case base for capitalizing cases and reusing them during a new modeling, and a reference models base containing models according to different types of enterprise domain. For elaborating the reference models, a production typology is done. This typology is improved by the addition of new criteria.

2.2.2 GRAISUC

GRAISUC is a module used for managing the choice of an ERP or SCM tool for an enterprise. It is composed of two sub-modules SpeMM and SpeCM. The Specification Management Module (SpeMM) is used for choosing the appropriate ERP or SCM Tool of an enterprise. The specifications obtained are capitalised in the Specification Capitalisation Module (SpeCM).

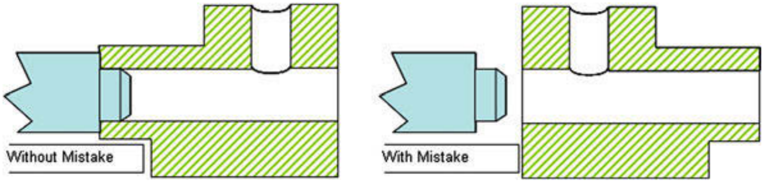


Fig. 4 Poka Yoke

The development of a module to help in the choice and implementation of a supply chain tool necessitates the acquisition of specialist knowledge. Some of the concepts developed for the expert system GRAIXPERT are reused for this new module (Dossou and Mitchell 2009). These concepts are used during the different phases leading to the choice and the implementation of a SCM tool. For instance, the reference models and the rules are used during the analysis and the design of the future enterprise models.

In this process, we compare a reference model of the enterprise domain with the results from the modelling/diagnostic. If the total of modifications is inferior to 0.25 we can go directly to the detailed design of the decisional system. Otherwise, a preliminary design is carried out. If the total exceeds 0.75 we can go directly to the stage of design of the GRAI networks-the final sub-stage. This design process is managed by the interaction between GRAIXPERT, GRAISUC and GRAIKERN.

This interaction is of course managed by GRAIManager. Then specifications are extracted from the design models obtained in order to define the most suitable enterprise handbook for choosing an SCM tool. CBR could be used for comparing the future specifications with those obtained during a previous case studied.

2.2.3 GRAIQUAL

GRAIQUAL is a module used for managing quality approach implementation or quality improvement in an enterprise. It contains two sub-modules IMM and QUALKBM. The Improvements Management Module (IMM) is used for managing the different quality action plans of the enterprise. It contains different quality tools (Dossou and Mitchell 2011a). In the IMM we can notice for example tools such as SPC (Statistical Process Control), or Poka-Yoke. Poka Yoke (a mistake proofing system) is a relatively simple means to prevent human error (Fig. 4). Mistake proofing systems exist in everyday life as, for example, the gas pump nozzle for leaded petrol cannot be inserted into the petrol tank orifice of cars using unleaded petrol. There is nothing new in this concept. What is new is the generalisation of its use. They can be simple: a template in which only parts with the correct dimensions fit, photoelectric cells detecting the presence of a shape on a conveyor etc.

The Quality Knowledge Base Module (QUALKBM) is being elaborated for containing the rules related to quality certifications in order to use them for improving or elaborating quality in an enterprise. This method is used for organising the global implementation of a quality approach, for managing the associated quality system and improving the enterprise performance. In this section we also look at the concepts which form the basis of the GRAILQUAL. Some of them were developed for GRAIXPERT and reused for this new module (Dossou and Pawlewski 2010). Reference models, rules and old case are reused.

For instance, the concept of reference model allows with GRAIXPERT to define according to the domain the optimum realizable in terms of the quality approach and the implementation of certification. For example this could be the management of the process and all the necessary stages to obtain ISO 9000 version 2000 with the entire implementation phase and follow up. The discovery phase and the mastery of the vocabulary and principles (ISO 9000), the quality assurance demands (ISO 9001) and the main axes for the improvement of enterprise performance (ISO 9004) are established. The established rules are exploited in the initial audit (modelling of the existing system) as well as in the phases concerning application of norms and the internal audit (analysis and design). Adding a case study enables to enrich the data base comprising the different studies undertaken in order to render the use of CBR (Case Based Reasoning) more efficient.

In order to manage all the GRAI Quality approach and the design of the 'TO BE' models the problem resolution method developed for the expert system GRAIXPERT is used. It is based on several reasoning mechanisms: CBR (Case Based Reasoning), Decomposition, Transformation and direct correspondence [10]. Once defined the architecture allows to bring to the company all the expertise in the field of quality, continuous improvement tools and certification procedure.

One of the most important factors of the model developed is equally the opportunity by means of a comparative study to show to the decision makers of the company the interest in setting up a procedure for quality, continuous improvement, or certification by carrying out a cost study in non quality. Investment in quality management is always profitable in the medium term, even if decision makers often demand instant results. The economic and financial arguments to convince them are made more credible by the use of this module.

For developing GRAIMOD and these modules an intelligent CAD systems theory was used and a problem solving method combining different reasoning (CBR, decomposition, direct correspondence, transforming reasoning) was elaborated. The CBR is combined with the multi-agent theory for realising the modules. JADE (Java Agent Development Framework) technology which implemented multi-system agents with the standard FIPA-ACL language (Foundation for Intelligent Physical Agents—Agents Communication Language) is chosen for this development. The question now is how to use this new tool for improving effectively the enterprise performance but also according to the changes of the world how to take into account the impact of environmental demands on the enterprise supply chain.

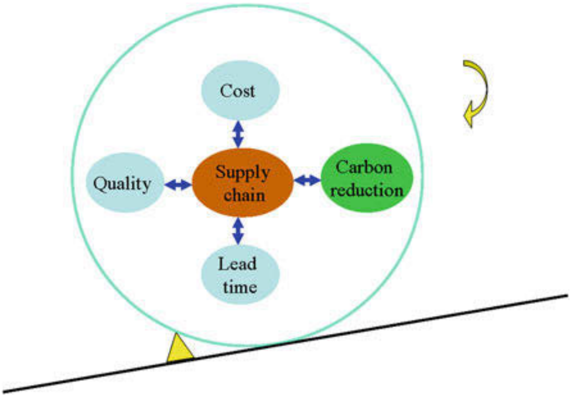


Fig. 5 New main criteria for enterprise performance

3 Carbon Footprint : A New Criterion of Enterprise Performance Improvement

The main criteria of performance are cost, lead time and quality. It is clear that there is a strong relation between these criteria. For instance, the improvement of quality facilitates the respect of lead time and reduces the cost of the product. But this improvement of quality also implies nowadays the respect of environmental demands. The new international context imposes upon the enterprises the need to adapt for being sustainable and green (Shamah 2009). In France, especially SMEs (Small and Medium Enterprises) recognize the necessity of this change but have not been able to make changes because of the cost related to environmental operations (Dossou and Mitchell 2011b). The integration of a criterion representing sustainable development is necessary for defining the new optimum for enterprises and showing them how their performance will be improved. We propose to use Carbon management as the fourth enterprise criterion (Fig. 5). Then, this criterion combined with quality, cost and lead time will really improve the enterprise and particularly the supply chain (Dossou and Mitchell 2010).

For each part of the supply chain everything is done for making the enterprise sustainable. So the three main performance criteria are highly related to carbon management. The objective is to use different techniques and methods for reducing carbon in each part of the supply chain (Dossou and Mitchell 2011a). In reality enterprises need to assess dependence on fossil fuels, anticipate fluctuations in energy prices, and limit the impact of the activity on the environment.

Even if researchers do not agree on the degree of damage to the planet caused by human beings, it is now clear that each enterprise has to reduce carbon levels. Some recommendations are generally made to quantify emissions and anticipate actions to manage carbon emissions: reduce emissions related to raw materials, reduce emissions related to energy consumption, reduce emissions related to waste, use alternative means of transport and reduce energy emissions.

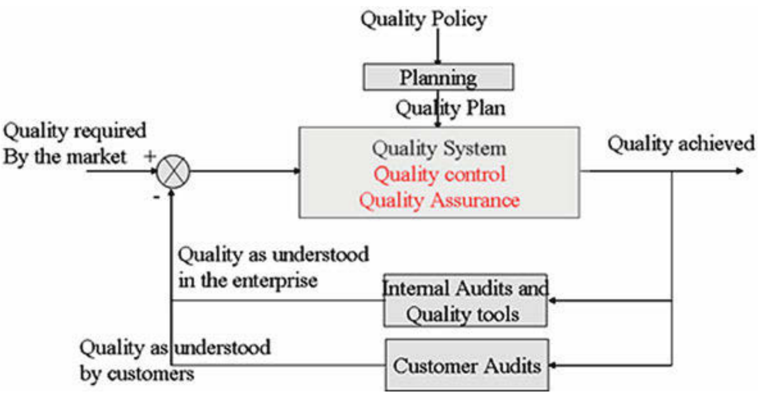


Fig. 6 Improved quality system

These points are crucial and need to be developed. Let us focus on waste management and transport. For instance, waste management is for enterprises a constraint in terms of cost and time without any added value. But, for example, waste in enterprises accounts for more than 50% of total waste produced in France. It means that for environmental reasons, it is essential to organize the management of waste. We could propose that enterprises integrate new ways of waste management such as collaboration, pooling and optimization of transport resources.

GRAIQUAL, one of GRAIMOD modules, allows to improve each part of the supply chain by using well-known quality tools (Fig. 6).

u(t) is the representation of the input (it means the quality required by the customer), v(t) the representation of the output, g(t) the function associated to the system in question (the quality system) and k(t) the function of the feedback (customer and internal audits). Laplace transforming could be used for formalizing this system. If e(t) is the difference between the quality required and the quality comprehended by customers and people in the enterprise, then the objective is to reduce this difference to zero. We can calculate the transfer function as follows:

$$\begin{aligned} &V(p) = G(p) * E(p) \\ &E(p) = U(p) - V(p) * F(p) \\ &\textit{then} \quad V(p) = G(p) * [U(p) - V(p) * F(p)] \\ &V(p) * [1 + G(p) * F(p)] = G(p) * U(p) \\ &\textit{so} \ \frac{V(p)}{U(p)} = \frac{G(p)}{1 + G(p) * F(p)} \end{aligned} \tag{1}$$

Then the temporal relation between v(t) and u(t) could be deduced. This loop will be applied to each part of the supply chain. A zoom on the procurement part and the relation with suppliers allows to define a vector q_p associated to the product, and then to able to quantify the local optimum for this supply chain part and simultaneously take into account the impact on the environment. The best quality of raw material could be chosen according to lead time. An economic study allows the choice of the best raw material not only in terms of cost performance of the supply chain but also in respect of the environment. The optimization of the global supply chain is achieved by using a set of software adapted to the enterprise helping it to react more quickly and to meet customer's demands. The goal is to be able to guarantee to the customers the delivery date and quality of the product and furthermore to reduce costs. It means the management and optimization of each part of the supply chain from suppliers of suppliers to customers of customers, but also the integration of all the chain. It is essentially the synchronization of the industrial, logistic and commercial processes, the reduction of information-handling and decision-taking cycles, and the reduction in enterprise process complexity. We can deduce that the choice of these tools is crucial for the enterprise. The addition of the environmental dimension also complicates the situation. The use of GRAISUC allows to facilitate the improvements of the supply chain and to choose and implement the appropriate SCM tool for the enterprise.

Cost and lead times are also optimized in the same way by choosing a SCM tool for the enterprise in order to manage the whole supply chain from the suppliers to customers. Indeed, for each sub-part of the supply chain, we can define a type of quality and measure the level of quality.

4 How to use GRAIMOD for Improving the Sustainable Supply Chain

We consider the set of supply chain E as an vector space. We can define L_1 an endomorphism of E and u a vector of E associated to a given supply chain (an object O). We also define u_k the vector of E associated to the sub-object O_k, u_k being a basic vector of L_1. Each supply chain is improved by optimizing the main performance criteria such as quality, cost, lead time. For quality criterion, each vector u_k corresponding to a given supply chain sub-part will be composed of vectors q_f, q_p, q_{pr}, q_s associated respectively to the main aspects of quality. The vector q_f represents Quality of suppliers, q_p Quality of products, q_{pr} Quality of process, and q_s global Quality of the system (Dossou and Mitchell 2009). These vectors are defined for each sub-part and indicate the global state of the sub-part according to the performance criterion Quality. We obtain the following Eqs. (2) and (3):

$$L_1(u_k) = \sum_{l=1}^{4} (\alpha_l * q_l) \tag{2}$$

$$L_1(u) = \sum_{k=1}^{n} \left(\lambda_k * \left(\sum_{l=1}^{4} \alpha_l * q_l \right) \right) \tag{3}$$

The following step is the design and local optimization. The global optimization objectives are detailed in local attainable objectives for a sub-part. An optimization of criteria is obtained for each supply chain. The coefficients α_l associated to vectors defining u_k are optimized by using the reference models defined in GRAIQUAL. The basic values λ_k associated to each sub-part are implicitly optimized and by deduction of the sub-part. We transform by successive iterations the sub-part O_k into designed sub-part O_k^c.

Indeed, we define a vector space F associated to the designed object O^c. It has the same dimension as E. Let us also define L_2 a linear application from E to F which transforms each basic vector u_k associated to the object O_k into a vector v_k associated to a designed sub-object O_k^c as follows (4) and (5):

$$v_k = L_2(u_k) = \delta_k * u_k \tag{4}$$

$$L_2(v) = \sum_{k=1}^{n} \sigma_k * v_k \tag{5}$$

The validation of the optimization of all the sub-objects implies a re-composition stage. It is clear that the sum of local optima is not necessarily the global optimum. In addition to the sum, this phase also guarantees coherence between all the defined optima, according to the existing reference models. The design solution of the object O is obtained by combining different partial solutions obtained for the sub-objects O_k and by keeping the coherence of the set.

We obtain the following Eq. (5):

$$O^c = \bigcup_{k=1}^{n} O_k^c. \tag{6}$$

As its name suggests, GRAIQUAL is used for managing different aspects of quality. It allows to analyze the quality approach (if it already exists) of an enterprise, and to propose an improvement process, action plan in conformity with reference models along with existing quality tools in GRAIQUAL. The defined process of quality acts on each part of the supply chain.

We can consider that for radically improving the performance of the supply chain, we need to carry out the same transformations based on the other performance criteria. In reality, the definition of a global optimum in terms of quality is not separable from an improvement to cost and lead time. Indeed, the elimination of defects in the manufacturing of a product for example, leads to reduced production and transport costs in order to satisfy customers and avoid penalties or claims due to the bad quality of products. It also improves the manufacturing process and thus reduces lead time. The implementation of a global quality approach greatly influences the performance of the supply chain.

The different aspects of quality are studied. Then each part of the supply chain is improved and logically the global supply chain. But simultaneously, the different reference models contained in GRAIQUAL in order to implement certifications could also be used for respecting the environment. The consequence is that the implementation of the certification ISO 14001 is generally obtained.

The different phases of the implementation are managed with GRAIQUAL. This theory is coherent with the organization of new production systems in order to respect sustainable development expectations.

The application of these different types of quality improvements allow to simultaneously improve environmental and supply chain performance.

The improvement of the supply chain corresponds to the optimization of the triptych quality, cost and lead time. Carbon management has to be added as a new criterion because of the impact of environmental demands and sustainability on future supply chains. Three steps of multi-criteria combination are defined:

- The first one allows to optimize lead time by taking into account all the parameters reducing delivery date. It means the optimization of lead time according to planning and organization, product, and process of the chosen part.
- The second step is integration of the four criteria (quality, lead time, cost and carbon management) for each part of the supply chain for finding a real optimum corresponding to the particularity of the enterprise. The defined reference models associated to each domain could be adapted to the enterprise in order to obtain the result envisaged.
- The last level is about the global supply chain for integrating the different parts and their local optima. The consequence of this step is the creation of a real coherence between the study of each part.

L_i is the lead time (lj is the lead time obtained by taking into account one parameter in each domain) and O_i is the Optimum (integrating quality Q_i, cost C_i, lead time L_i, and carbon management S_i) associated to one part of the supply chain. O is the global optimum of the supply chain.

$$\begin{aligned} L_i &= \sum_{j=1}^{n} \alpha_j * l_j \\ O_i &= \beta * L_i + \lambda * C_i + \gamma * Q_i + \mu * S \\ O &= \sum_{i=1}^{m} \eta_i * O_i \end{aligned} \tag{7}$$

Then GRAIQUAL as shown, contains tools for really transforming the supply chain in order to improve each performance criterion and integrate them.

Let us now focus on the carbon management criterion and its constraints. The objective for the enterprises is to use the opportunities to optimize waste management by reducing cost. The regulations relating to waste are constraints for enterprises, so it is obvious that they have to reorganize each part of their supply chain according to this new approach. Waste management has to be organized step by step: identification of potential partners, identification of partners having the same waste typology, knowledge of recycling domain, definition of partner's policy, economic and environmental validation of the optimized flows (carbon impact, tone per km, empty return rate, load factor….).

The second point is transport. In France the use of road transport has not ceased to expand over the last 20 years. But we know how ecologically expensive it is to use road transport for procurement or for dispatch. So it is interesting to use alternative transport: railway, air, maritime, or waterways. Nowadays, road transport represents 85% of merchandise traffic compared to 58% in 1984. It means that we have an increase in non ecological transport use. The problem is that there is no suitable alternative solution for short distance transport. The potential idea which could be interesting is to use the tramway network or local railway for distributing products directly to enterprises.

For long distances we do have alternatives. The increase in the price of oil and gas and the ecological constraints encourage the research of other viable solutions. We have for example the use of high speed trains for transporting products previously transported by truck or plane. The combination of rail and road appears a clear way forward if we use electric motors for road vehicles. Electric trucks could be integrated in the environmental development of a town replacing current diesel-driven trucks. There are other alternative motors being developed but their efficiency still needs to be confirmed.

The following examples allows to illustrate this last section and facilitates showing how to make the best choices using GRAIMOD to make enterprises and their supply chains sustainable.

5 Examples

Three examples are presented in this section. The first one is directly related to procurement and dispatch improvement on a supply chain. The second is about railway as an alternative optimization solution in a port. And the third studies the case of the use of tramway as an alternative solution in the optimization of enterprise transport in a city. The three examples take into account the necessary carbon reduction and increase the global enterprise performance.

5.1 Sustainable Supply Chain

The first example concerns an enterprise created in 2005 and composed of three hypermarkets. This enterprise is located in the west of France near Nantes. The three hypermarkets are in the outskirts of Nantes employing about 200 people. Each hypermarket was autonomous in order to be reactive and adapted to the desires of their local customers. The enterprise had a turnover of 85 million € in 2010 and the customers are essentially middle class. It means the necessity to have product with a high level of quality at a reasonable price respecting environmental demands, and sustainable philosophy. The impact of the economic crisis on this enterprise was severe, the enterprise loosing 40% of its customers in 2010. Then moreover the social and economic situation of the company was very difficult.

GRAI Methodology and the concepts of GRAIMOD allow to reorganize this enterprise and to transform it in order to be competitive and adapted to the market. The manager of the enterprise had a strong conviction that the market is the correct one and is reluctant to change it, the philosophy oriented to green and sustainable organization was obvious and right for him. But he was also a business man and wanted to make profit with its enterprise. The economic environment and the actual context of the enterprise impose the elaboration of a new organization and the optimization of the whole supply chain. The main problems were about respect of lead time (the products have to be on time in the hypermarket available to customers), quality of products and carbon management.

For this company a modelling of the existing situation was carried out in order to improve this enterprise. First of all, interviews were done, in order to acquire the context of the study. Then, a modeling phase allowed to obtain models according to GRAI methodology. Some observations of the enterprise process were done for improving the production cycle. The information obtained enabled to elaborate actigramme models, GRAIgrid and GRAInets of the existing system, which, in turn, allows to detail links between services of an enterprise. These models represented a photo of the company and from these pictures malfunctions were detected. These inconsistencies made it possible to deduce the strengths and weaknesses and the points to improve within the company. An action plan was drawn up in accordance with the new development strategy of the company. The most important are the following:

- Reorganisation of procurement, purchasing and dispatch systems within 2 months,
- Setting up of a global quality policy within 1 year,
- Preparation and the setting up of the environmental certification ISO 14001 within 1 year.
- Preparation and setting up of the certification ISO 9000 within 1 year,
- Preparation and setting up of the certification OHSAS 18001 within 3 years,

Here we will only focus our attention on procurement, purchasing and dispatch. The quality system GRAIQUAL, a sub-module of GRAIMOD, was used. This module contains norms and rules of quality. The supply chain was divided into different parts. The first part concerns the suppliers and their management. It means purchasing but also procurement. Indeed, the improvements were in the definition of a local optimum on quality (elaboration and implementation of Suppliers Quality Assurance) but also about lead time, cost and carbon footprint reduction. Each hypermarket had its own suppliers being autonomous. They had to manage alone and the negotiations with suppliers were very harsh. So each hypermarket started buying products from other countries (China, Romania, Poland, Spain,…). It means a reduction of cost but an increase in lead time and carbon footprint, and a decrease in quality due to long transport. The enterprise had a hub for dispatching products to the hypermarkets. So this hub had to manage three different purchase plans. The service had difficulties satisfying everybody and had little freedom of action.

For instance, we proposed to define only one purchase service and to reorganize the three procurement services in order to be more efficient. The market of the enterprise is composed of the middle class, so cost is not always the first criteria to take into account. They need to be sure that the products are green and sustainable and for a specific product to be available when they want. They need to be sure of being able to purchase their favorite product in any of the three hypermarkets. So the best way is to unify the requirements of each hypermarket in only one defined procurement plan and to exploit this plan for obtaining a single purchase plan. Then, the purchase service has to do sourcing and selecting the best supplier not only by respecting cost reduction but also mainly by decreasing the level of carbon and choosing the best quality of product. This proposition is interesting because it favors the choice of local producers instead of low cost producers. The transport is reduced, the increase in the price of petrol could be managed this way. The traceability of the product is used for knowing exactly the way of production and validating the quality and the sustainability of the product. The global purchase allows to place a large order and to be able to better negotiate with suppliers. A sustainability chart is produced for discussing with suppliers, and allows to elaborate with them collaboration. This type of organization could also be used for defining the marketing plan of the enterprise for promotion and obtaining new customers by paying attention to the product local origin and the global sustainable organization. The optimization obtained had an impact on cost and lead time, but we also tried to respect environmental demands and reduce carbon levels in order to obtain a sustainable chain. For example, we organized the sourcing and selection of suppliers for choosing partners who have ISO 14001 certification. This constraint allows not only to respect the environment and reduce the carbon footprint but also to improve the quality of products. The enterprise will propose to customers an environmental contribution for each product. This means that some cost reduction has to be made in order to be competitive and to incorporate the ecological dimension.

The processes necessary for the certification ISO 9000 and ISO 14001 have been successfully launched. All products conform to health and safety regulations in place for the food industry as well as any legislation relating to the health and safety of the personnel and the environment, designed to satisfy the customer. To achieve these objectives the company has set up a formalised quality system in order to conform to the certification norms. It has also identified risks using tools such as HACCP calculating the risks for the product and guarantees the control of these risks. The industrial activities conform to existing legislation regarding the protection of the environment. The impact on the environment is minimised by using and researching ways to have a reasoned use of resources and protection of the environment in the framework of sustainable growth. To achieve these goals the company is directly responsible for the environmental impact of its activities.

The implementation of OHSAS 18001 is under way.

The use of GRAIQUAL and its reference models and norms allows to improve the performance of this enterprise and a partial evaluation shows an increase of 27% in turnover due to the reorganisation. A detailed study will be done at the end of the year for showing the real impact. But the management of the enterprise is very pleased with the new organisation and very proud of the sustainable and green touch.

5.2 Sustainable Transport

This example presents the difficult issues of transport for enterprises and one way for solving it by using GRAIMOD. The main mode of transport in France is road by using trucks. This kind of transport has the advantage of being very simple because of the quality of roads in France. But, with the steady increase in the price of petrol, we need alternative solutions. The negative impact of the use of trucks on our planet is also a second reason for finding alternative solutions. For enterprises nowadays relocation is not necessarily the best way for improving their performance. Relocation implies finding countries with a low cost of working force in order to be competitive. This kind of working is under scrutiny because of the transport cost and some enterprises are returning to local promises for reducing transport cost and consequently carbon emissions. Transport performance is based on five points:

- Highest load factor possible.
- Minimizing distance: we have to optimize transport plans and scheduling.
- Optimization of resources and drivers: transport and waiting times.
- Definition of purchasing policy respecting the environment: quality of service and cost.
- Monitoring: quick identification of deviations in terms of quality and invoicing.

For instance, the enterprise has to use algorithms for optimizing delivery between manufactures and hubs, or delivery organization (Krushkal, Penalties, dead point analysis algorithms…). The use of these algorithms is done by adding sustainable development as the main constraint. GRAIMOD contains reference models, norms and certifications processes, and algorithms for improving enterprises. Special attention is paid to the sustainable part by using the fourth criterion: carbon management.

For instance, an enterprise located in Paris and specialized in electrical products needs to buy raw materials from other countries (China, Taiwan,…). According to the previous explanations we first suggested that this enterprise find local suppliers, but the possibilities of delivering by local suppliers were not sufficient. So the enterprise had to import the rest of raw materials. Currently the enterprise uses trucks for transporting the products from the port of Le Havre to the center of Paris. We proposed to use the railway solution. Indeed, the products were transported in containers on the boat. These containers just had to be adapted and then the transport could be done directly by train to the center of Paris thus reducing carbon. Two problems remained to be solved: how to optimize the loading of containers on the train for reducing the cost and how to manage the transport from the railway station to the enterprise.

For the loading of containers, efficient algorithms are being developed in laboratory for finding the optimum. For the transport from railway station to the enterprise, we proposed to use shuttles for this small distance in order to find a suitable alternative.

The improvement in this enterprise's transport and its adapting to sustainable development is underway but the main problem is now global cost reduction in order to totally convince to have the total backing of the management board.

5.3 Sustainable City Organization

This third example presents an example relating to global management in a city. As we know the management of cities by introducing sustainability and green attitudes is in fashion nowadays. But the impact of this behavior on our planet is very important. It has become essential to nurture this responsible attitude and encourage more towns to follow the same path. More cities are trying to reduce their carbon footprint, by choosing this criterion as a performance criterion. For instance we have:

- Use of green and sustainable raw materials for building houses and public building
- Use of sustainable and alternative solutions for powering these buildings (solar, geothermal energy…)
- Reduction in volume of traffic (tramway, bicycles, toll, buses, increase in parking cost,…)
- Forbidding Trucks in the city centre
- Development of pedestrian streets or precincts
- Waste management

These cities have a global policy for sustainable development. Let us take the example of Paris or London relating to bikes. The cities decided to set up bike docking stations throughout in order to facilitate the movement of people. But this step forward will certainly imply clear logistics issues. How best to organize each docking station? Each person who hires a bicycle needs to be satisfied and be able to leave his bike at a convenient station anywhere in the city. Bike ways, green ways and super highways have to be developed to enable users to go everywhere. Some stations need a greater quantity of bikes because of their proximity to transport hubs such as railway stations. Its means that people coming from the railway station could be able to immediately take a bike to proceed to their destination. Other stations are much visited by tourists and would also need to meet the high demand for cycles. So the frequency of use, the capacity, the procurement, the global flow management are key criteria that could be take into account by using GRAIMOD and the four main criteria: cost, quality, lead time and carbon management.

It is evident that the use of bikes is green and sustainable. But the link with lead time is also important. Indeed the customer who is a tourist or resident of Paris needs to be where he wants on time. So he has not to wait for a bike. The cost of transport is reduced because he does not have to pay for a taxi or any other transport and the quality of service has to be increased. The quality of bikes has to be the best. For instance, a solar motor could be added to the bike for helping people reduce the physical effort. GRAIMOD also contains optimization algorithms for managing the global bike park and its constraints.

An industrial example could be presented. The city of Nantes is thinking about how to forbid trucks from moving in the town without penalties for enterprises and commerce. According to the green and sustainable attitude this town has implemented a very convenient tramway network to enable passengers to go everywhere in the city. The objective was initially to reduce car traffic. However, now they are actively looking at the possibility of also using this network for the transport of goods. GRAIMOD with the four criteria could also be used on this project for finding the optimum using the tramway. It is clear that this solution is sustainable. But the feasibility has to be studied in detail. How to manage the traffic for transporting raw materials to enterprises and in return transporting products to customers by reducing cost, lead time and increasing quality? How to manage the use of the railway for both passenger and goods trams at the same time without inconveniencing passengers? How to load and unload the containers and transport the products for companies? We choose to use GRAIMOD for finding and developing solutions for this interesting project. Many ideas are being studied such as the construction of new stopping areas for goods trams in order to prevent them from causing disruption to passenger tramways (Fig. 7).

The frequency, the speed, the size of wagon, and the power used are some of the many different questions which have to be addressed. The project is underway and a solution will be proposed for the global project in the near future.

6 Conclusions and Further Research

All European enterprises have to resist economically and financially the present crisis. However, they have to also be ready for the future economic growth in Europe. In this chapter GRAI Methodology is used as one way for helping enterprises to improve themselves for being competitive faced with the new economic context. GRAIMOD, the software being developed for supporting the methodology, has been presented and illustrated. Special attention was paid to the use of carbon management as the fourth main enterprise performance criterion. Indeed, the three main performance criteria (cost, quality, lead time) are completed with Carbon management, in order to anticipate the constraints of the future supply chain (horizon 2015). So, a new optimum integrating this criterion is defined.

The concepts presented were illustrated with three examples on sustainable supply chain, sustainable transport and sustainable city organization. The use of

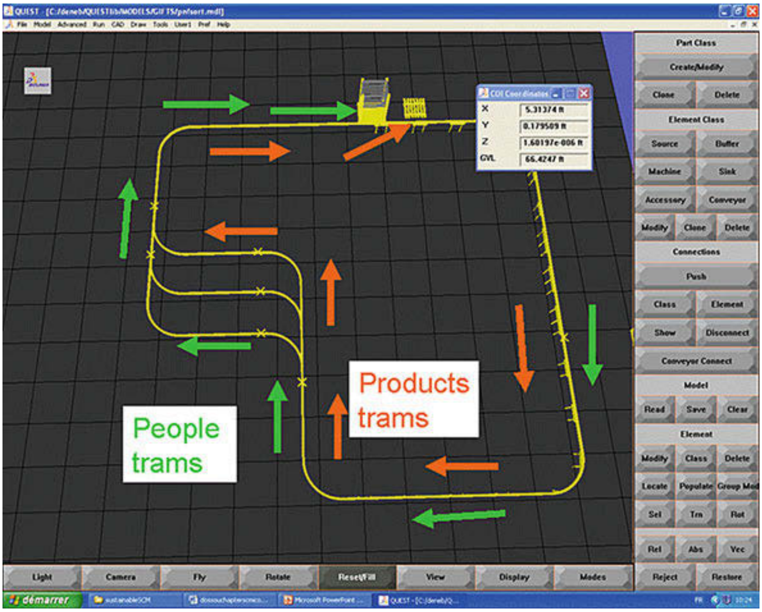


Fig. 7 Optimization of Tram flows (example of simulation)

the concepts presented allows to respect environmental demands and norms, to make a real contribution to the saving of our planet. Moreover, it provides a unique opportunity for promoting the enterprise and its values and finally to improve enterprise performance. Sustainability is surely the best way forward for our enterprises but they need to be convinced and we have to show them how it would be better for them to acquire this wonderful philosophy.

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Sustainability in the Supply Chain: Analysing the Enablers

Katarzyna Grzybowska

Abstract The purpose of this chapter is to identify the enablers to sustainability in the Supply Chains and to understand their mutual relationships. Interpretive structural modelling was applied to present a hierarchy-based model and identify the contextual relationships among these enablers. This chapter defines sustainability, the Supply Chain (metastructure) and presents the ISM Methodology. The chapter presents the mutual relationships among the enablers of sustainability in the Supply Chain. Research shows that not all enablers to sustainability in the Supply Chain require the same amount of attention. A group of enablers that have high driving power and low dependence, requiring maximum attention exists. This classification will help Supply Chain managers to differentiate between independent and dependent variables. This classification will help them to focus on those variables that are most important for the transformation of the Supply Chain in sustainability.

Keywords Sustainability · Supply chain · Sustainable supply chains · Structural self-interaction matrix · ISM methodology

1 Introduction

A supply chain is a network of organizations that are involved in different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer (Christopher 1998). The Supply Chain is a

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metastructure (Grzybowska 2010b). A metastructure is an intermediate form between a single enterprise (microstructure) and global economy (macrostructure). A metastructure is characterized by a dynamic holarchy of cooperating holons (commercial entities). They are parts and wholes at the same time (Wilber 2007). The enterprises join the Supply Chains and contribute various, unique capacities or skills (a characteristic of holons). The greater the supply chain grows, the less coherent and lacking close relationships it is (Grzybowska 2010a). In turn, this results in a situation in which in such a metastructure's connections and dependencies may vary in permanence. One differentiates permanent links (the so-called core supply chain) and dynamic ones which change depending on the task carried out (the so-called temporary links). After cooperation is concluded, the temporary links become disconnected from the supply chain cooperation. The Supply Chain is a concept designed to manage entire supply chains consisting of numerous participating organizations (Mentzer et al. 2001, p. 7).

The concept of sustainable development is the result of the growing awareness of the global links between mounting environmental problems, socio-economic issues to do with poverty and inequality and concerns about a healthy future for humanity (Hopwood et al. 2005, p. 39). Lee (2000), p. 32 has argued, 'sustainable development is an unashamedly anthropocentric concept'. The World Business Council for Sustainable Development defines sustainability as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Peters et al. 2007). According to Elkington, "a business needs to measure and report economic, social, and ecological business performance in order to achieve corporate sustainability" (Hamprecht 2006, p. 9).

But what is sustainability in the Supply Chain (or the Sustainable Supply Chain (SSC), the Environmentally Responsible Supply Chain, Green Supply Chain (GSC), green logistics and reverse logistics)? Sustainability in the Supply Chain is a key component of corporate responsibility. Sustainability in the supply chain is the management of environmental, social and economic impacts, and the encouragement of good governance practices, throughout the lifecycles of goods and services (Supply Chain Sustainability a practical Guide for Continuous improvement 2010). Sustainable Supply Chain is the management of raw materials and services from suppliers to manufacturer/service providers to customers and back with the improvement of the social and environmental impacts explicitly considered.

The supply chain has been traditionally defined as a one-way, integrated manufacturing process wherein raw materials are converted into final products, then delivered to customers. The change environmental requirements affecting manufacturing operations, increasing attention is given to developing Environmental Management (EM) strategies for the supply chain—Green Supply Chain (Beamon 1999). While traditional logistics seeks to organise forward distribution, that is the transport, warehousing, packaging and inventory management from the producer to the consumer, environmental considerations opened up markets for recycling and disposal, and led to an entire new sub-sector: reverse logistics (Rodrigue et al. 2001, p. 2). While the term reverse logistics is widely used, other names have been applied, such as reverse distribution, reverse-flow logistics, and green logistics (Byrne and Deeb 1993).

The growing concern about sustainable development has an increasingly greater impact upon the Supply Chains and SCM. As stated by Linton et al. (2007), p. 1078: sustainability also must integrate issues and flows that extend beyond the core of SCM: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life.

The Sustainable Supply Chain requires a broadened approach to the Supply Chain. In the case of sustainable or "green" SCM, supply chain members are encouraged to fulfil customers' needs concerning ecological or social products (Zhu and Sarkis 2004, p. 265).

The main objectives of this chapter are:

- to identify and rank the barriers to adoption of sustainability in the Supply Chain practices in business,
- to find out the relation and interaction among identified barriers using ISM.

2 Enablers of Sustainability in the Supply Chain

An enabler is defined as "as one that enables another to achieve an end" where enable implies to make able; give power, means, competence, or ability to (Merriam-Webster). An enabler is considered as a variable that enables (ability to) the attainment of the Sustainable Supply Chain. This definition is consistent with the use of the term enabler in ISM models (Raj et al. 2008), growth enablers in construction companies (Bhattacharya and Momaya 2009), information technology (IT) enablement in the Supply Chain (Jharkharia and Shankar 2004), enablers of reverse logistics (Ravi et al. 2005), IT enablers for Indian manufacturing small and medium enterprises (SMEs) (Thakkar et al. 2008), supply chain performance measurement system implementation (Charan et al. 2008).

In this chapter, 16 important variables (enablers) that inhibit sustainability in the Supply Chain, are selected based on a review of the literature and through discussions with practicing managers in operations and management functions from manufacturing industries (Table 1).

3 ISM Methodology

It is generally felt that individuals or groups encounter difficulties in dealing with complex issues or systems. The complexity of the issues or systems is due to the presence of a large number of elements and interactions among these elements. The presence of directly or indirectly related elements complicates the structure of the

Table 1 Sustainability in the supply chain—enablers (Svensson 2007; Min and Galle 1997a; Zsidisin and Siferd 2001; Zhu et al. 2007; Min and Galle 1997b)

No.	Enablers
1	Commitment from top management
	Buyer awareness
	Supplier awareness
2	Adequate adoption of reverse logistic practice (Environmental Performance):
	Reduction of air emission
	Reduction of waste water
	Reduction of solid wastes
	Decrease of consumption for hazardous/harmful/toxic materials
	Decrease of frequency for environmental accidents
	Improve a company's environmental situation
3	Eco-literacy amongst supply chain partner (Green purchasing):
	Providing design specifications to suppliers that include environmental requirements for purchased items
	Cooperation with suppliers for environmental objectives
	Environmental audit for suppliers' inner management
	Suppliers' ISO14000 certification
	Second-tier supplier environmentally friendly practice evaluation
4	Corporate social responsibility
	Environmental standards
	Auditing programs
5	Mutual transparency:
	Development of alliances—horizontal, vertical
	Collaborative practices
	Instantaneous information sharing via Internet aimed at improving supply chain sustainability
6	Market demand
	Environmentally friendly products
7	Logistics asset sharing
	The joint use of a warehouse by two or more actors of the SC
	Deliveries optimisation for two or more customers
8	Adoption of a cleaner technology (a logistics solution using the so-called clean transport modes):
	Barge
	Multimodal
	Piggyback traffic for deliveries to the points of sale
9	High level of supply chain integration
10	Partnership
	Partnerships to develop common sustainable solutions
	Pioneering experiences with ecological organizations, socially or environmentally involved non-governmental organizations (NGOs)
	Lobbies
	Adopt innovation
	Research and development (R&D)
	Suppliers' capability in product development

(continued)

Table 1 (continued)

No.	Enablers
11	Continuous improvement Training and development Learning-by-doing
12	Collective development of labels, standards, norms, best practices databases, existing guidelines, voluntary agreements, and private sectors initiatives for self-regulation
13	Waste management Biodegradation Nontoxic incineration Scrapping Product returns Source reduction Recycling Material substitution Reuse of materials Waste disposal Re-manufacturing Repair
14	Logistics organisation ensuring goods safety and consumer health (ex: via the set up of tracking and tracing tools all along the chain, the search for transport scheduling and routing optimisation) (ex: load factor improvement, optimisation of replenishment and deliveries, delivery trip reconfiguration, the integrated planning of both production and sourcing sites, etc.)
15	Cooperation with customers including environmental requirements Cooperation with customer for eco-design Cooperation with customers for cleaner production Cooperation with customers for green packaging Cooperation with customers for using less energy during product transportation
16	Eco-design Design of products for reduced consumption of material/energy Design of products for reuse, recycle, recovery of material, component parts Design of products to avoid or reduce use of hazardous of products and/or their manufacturing process

system which may or may not be articulated in a clear fashion. It becomes difficult to deal with such a system in which the structure is not clearly defined (Raj et al. 2008).

Interpretive Structural Modeling (ISM) is defined as a process aimed at assisting the human being to better understand and clearly recognize what one does not know (Farris and Sage 1975). The ISM process transforms unclear, poorly articulated mental models of systems into visible and well defined models. ISM is an interactive learning process. In this technique, a set of different directly and indirectly related elements are structured into a comprehensive systematic model. The model so formed portrays the structure of a complex issue or problem in a carefully designed pattern implying graphics as well as words (Singh et al. 2003; Ravi and Shankar 2005).

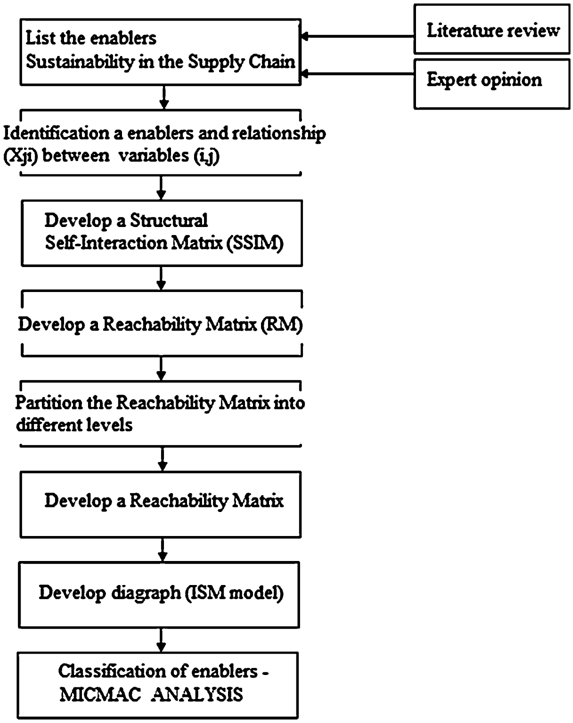

Fig. 1 Flow diagram for constructing an interpretive structural modeling; based on (Kumar et al. 2009)

Interpretive Structural Modeling was first proposed by Warfield (1976). It enables individuals or groups to develop a map of the complex relationships between many elements involved in a complex decision situation (Charan et al. 2008).

It is a method for developing the hierarchy of system enablers to represent the system structure (Sharma et al. 2011). Interpretive Structural Modeling is often used to provide a fundamental understanding of complex situations, as well as to put together a course of action for solving a problem. The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes (Ahuja et al. 2009).

The important characteristics of ISM are as follows (Sharma et al. 2011):

- This methodology is interpretive, as the judgment of the group decides whether and how the different elements are related.
- It is structural on the basis of mutual relationships as the overall structure is extracted from the complex set of elements.
- It is a modeling technique, as the specific relationships and overall structure are portrayed in a digraph model.
- It helps to impose order and direction to the complexity of relationships among various elements of a system (Sage 1977).

ISM is a powerful technique, which can be applied in various fields. Interpretive Structural Modeling is used by a number of researchers (Mandal and

Deshmukh 1994; Bolanos et al. 2005; Faisal et al. 2006; Ramesh et al. 2008; Faisal 2010; Sharma et al. 2011). The various steps involved in the ISM technique are represented in the form of a flow diagram (see Fig. 1).

The various steps involved in the ISM technique are as follows:

Step 1: Different enablers (or variables), which are related to defined problems, are identified.
Step 2: A Structural Self-Interaction Matrix (SSIM) is developed for enablers. This matrix indicates the pair-wise relationship among enablers of the system. This matrix is checked for transitivity.
Step 3: A Reachability Matrix (RM) is developed from the SSIM.
Step 4: The RM is partitioned into different levels.
Step 5: The Reachability Matrix is converted into its conical form, i.e. with most zero (0) elements in the upper diagonal half of the matrix and most unitary (1) elements in the lower half.
Step 6: Based upon the above, a directed graph (digraph) is drawn and transitivity links are removed.
Step 7: Digraph is converted into an ISM model by replacing nodes of the elements with statements.
Step 8: The ISM model is checked for conceptual inconsistency and necessary modifications are incorporated.

4 The Formation of Structural Self-Interaction Matrix (SSIM)

Identification of enablers. The elements of the system are identified which are relevant to the problem or issue and then achieved with a group problem-solving technique such as brain storming sessions. On the basis of the review of literature for sustainability in the Supply Chain, a total 16 enablers were identified.

After identifying and enlisting the 16 enablers through the review of literature and expert opinions, the next step is to analyse these enablers. For this purpose, a contextual relationship of "leads to" type is chosen. Bearing the contextual relationship for each enabler in mind, the existence of a relation between any two enablers (*i* and *j*) and the associated direction of this relation has been decided.

Contextual Relationship. From the enablers identified in step 1, a contextual relationship is identified among enablers with respect to which pairs of variables would be examined. This step transforms the list into a matrix and marks dependencies using expert opinions. After resolving the enablers set under consideration and the contextual relation, a Structural Self-Interaction Matrix (SSIM) is prepared.

Four symbols are used to denote the direction of relationships between the enablers (*i* and *j*):

- V: for the relationship from enabler *i* to enabler *j* and not in both directions;
- A: for the relationship from enabler *j* to enabler *i* and not in both directions;

Table 2 Structural self-interactive matrix (SSIM)

No.	Enablers	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	Commitment from top management	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
2	Adequate adoption of reverse logistic practice	A	O	O	X	A	O	A	O	O	O	O	O	O	A	
3	Eco-literacy among supply chain partner	O	V	V	V	V	V	O	O	V	V	O	O	V		
4	Corporate social responsibility	O	O	V	V	V	O	O	O	V	V	O	V			
5	Mutual transparency	O	V	V	O	V	O	A	A	O	O	A				
6	Market demand	V	V	V	O	V	O	O	O	V	O					
7	Logistics asset sharing	O	O	O	O	O	O	A	A	O						
8	Adoption of cleaner technology	A	A	A	V	V	O	O	O							
9	High level of supply chain integration	O	A	A	V	V	O	V								
10	Partnership	O	V	V	O	V	O									
11	Continuous improvement	O	O	O	V	V										
12	Collective development of lables, standards, …	O	V	V	V											
13	Waste management	A	O	A												
14	Logistics organisation ensuring good safety and consumer health	A	A													
15	Cooperation with customers including environmental	V														
16	Eco-design															

- X: for both the directional relationships from enabler *i* to enabler *j* and *j* to *i*;
- O: if the relationships between the enablers did not appear valid (enablers *i* and *j* are unrelated).

The first step is to analyse the contextual relationship of "leads to" type. Based on this contextual relationship, a Structural Self- Interaction Matrix is developed.

Based on the review of literature and expert's responses, the SSIM is constructed as shown in Table 2.

Based on the contextual relationships between enablers, the SSIM has been developed. To obtain consensus, the Structural Self-Interaction Matrix was discussed among a group of experts. Based on their responses, the SSIM has been finalized and it is presented in Table 2. The following statements explain the use of symbols in Structural Self-Interaction Matrix, e.g.:

- Symbol V is assigned to cell (1, 16) as enabler 1 influences or reaches enabler 16.
- Symbol A is assigned to cell (2, 16) as enabler 16 influences the enabler 2.
- Symbol X is assigned to cell (2, 13) as enablers 2 and 13 influence each other.
- Symbol O is assigned to cell (5, 16) as enablers 5 and 16 are unrelated.

Table 3 Initial reachability matrix

No.	Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Commitment from top management	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
2	Adequate adoption of reverse logistic practice	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	Eco-literacy among supply chain partner	0	1	1	1	0	0	1	1	0	0	1	1	1	1	1	0
4	Corporate social responsibility	0	0	0	1	1	0	1	1	0	0	0	1	1	1	0	0
5	Mutual transparency	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0
6	Market demand	0	0	0	0	1	1	0	1	0	0	0	1	0	1	1	1
7	Logistics asset sharing	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
8	Adoption of cleaner technology	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
9	High level of supply chain integration	0	0	0	0	1	0	1	0	1	1	0	1	1	0	0	0
10	Partnership	0	1	0	0	1	0	1	0	1	1	0	1	0	1	1	0
11	Continuous improvement	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
12	Collective development of lables, standards, …	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0
13	Waste management	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
14	Logistics organisation ensuring good safety and consumer health	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0	0
15	Cooperation with customers including environmental	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1
16	Eco-design	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	1

4.1 Reachability Matrix

Final reachability matrix. The next step is to develop the Reachability Matrix (RM) from the Structural Self-Interactive Matrix. This is obtained in two sub-steps.

In the first sub-step, the Structural Self-Interaction Matrix is transformed into a binary matrix (see Table 3), called the initial reachability matrix by substituting *V*, *A*, *X*, *O* by *1* and *0* as per the case. The rules for the substitution of 1s and 0s are as follows:

- If the (*i, j*) entry in the SSIM is *V*, then the (*i, j*) entry in the reachability matrix becomes *1* and the (*j, i*) entry becomes *0*.
- If the (*i, j*) entry in the SSIM is *A*, then the (*i, j*) entry in the reachability matrix becomes *0* and the (*j, i*) entry becomes *1*.
- If the (*i, j*) entry in the SSIM is *X*, then the (*i, j*) entry in the reachability matrix becomes *1* and the (*j, i*) entry also becomes *1*.
- If the (*i, j*) entry in the SSIM is *O*, then the (*i, j*) entry in the reachability matrix becomes *0* and the *(j, i*) entry also becomes *0*.

In the second sub-step, the final reachability matrix is prepared (see Table 4). The concept of transitivity is introduced so that some of the cells

Table 4 Final reachability matrix

No.	Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Driver
1	Commitment from top management	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	14
2	Adequate adoption of reverse logistic practice	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
3	Eco-literacy among supply chain partner	1*	1	1	1	0	0	1	1	0	0	1	1	1	1	1	0	11
4	Corporate social responsibility	1*	0	1*	1	1	0	1	1	0	0	0	1	1	1	0	0	9
5	Mutual transparency	0	0	0	0	1	0	0	0	1*	1*	0	1	0	1	1	0	6
6	Market demand	0	0	0	0	1	1	0	1	0	0	0	1	0	1	1	1	7
7	Logistics asset sharing	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
8	Adoption of cleaner technology	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	3
9	High level of supply chain integration	0	1*	0	0	1	0	1	0	1	1	0	1	1	1*	1*	0	9
10	Partnership	0	1	0	0	1	0	1	0	1	1	0	1	0	1	1	0	8
11	Continuous improvement	0	0	1*	0	0	0	0	0	0	0	1	1	1	0	0	0	4
12	Collective development of lables, standards, …	0	1	0	0	1*	0	0	1*	1*	1*	0	1	1	1	1	0	10
13	Waste management	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
14	Logistics organisation ensuring good safety and consumer health	1*	0	0	0	1*	0	0	1	1	1*	0	1*	1	1	0	0	8
15	Cooperation with customers including environmental	0	1*	0	0	1*	0	0	1	1	1*	0	1*	1*	1	1	1	10
16	Eco-design	1*	1	0	0	0	1*	0	1	0	0	0	0	1	1	1*	1	
	Dependence	6	10	5	4	9	3	7	10	8	8	5	12	12	12	10	5	–

Note 1* entries are included to incorporate transitivity

of the initial reachability matrix are filled by inference. The transitivity concept is used to fill the gap, if any, in the opinions collected during the development of the SSIM.

Table 5 Iteration 1

No	Reachability set	Anticedent set	Intersection set	Level
1	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15	1,3,4,16	1,3,4,14	
2	2,13	1,2,3,9,10,12,13,15,16	2,13	1
3	1,2,3,4,7,8,11,12,13,14,15	1,3,4,11	1,3,4,11	
4	1,3,4,5,7,8,12,13,14	1,3,4,6	1,3,4	
5	5,9,10,12,14,15	1,4,5,6,9,10,12,14,15	5,9,10,12,14,15	
6	4,5,6,8,12,14,15,16	6,16	6,16	
7	7	1,3,4,7,9,10	7	1
8	8,12,13	1,3,4,6,8,12,14,15,16	8,12	
9	2,5,7,9,10,12,14,15	1,5,9,10,12,14,15	5,9,10,12,14,15	
10	2,5,7,9,10,12,14,15	1,5,9,10,12,14,15	5,9,10,12,14,15	
11	3,11,12,13	1,3,11,12	3,11,12	
12	2,5,8,9,10,11,12,13,14,15	1,3,4,5,6,8.9.10,11,12,14,15	5,8,9,10,11,12,14,15	
13	2,13	2,3,4,8,9,11,12,13,14,15,16	2,13	1
14	1,5,8,9,10,12,13,14	1,3,4,5,6,9,10,12,14,15,16	1,5,9,10,12,14	
15	2,5,8,9,10,12,13,14,15,16	1,3,5,6,9,10,12,15,16	5,9,10,12,15,16	
16	1,2,6,8,13,14,15,16	6,15,16	6,15,16	

Table 6 Iteration 2–4

No	Reachability set	Anticedent set	Intersection set	Level
8	8,12	1,3,4,6,8,12,14,15,16	8,12	II
11	3,11,12	1,3,11,12	3,11,12	II
5	5,9,10,14,15	1,4,5,6,9,10,14,15	5,9,10,14,15	III
9	5,9,10,14,15	1,5,9,10,14,15	5,9,10,14,15	III
10	5,9,10,14,15	1,5,9,10,14,15	5,9,10,14,15	III
12	5,9,10,14,15	1,4,5,6,9,10,14,15	5,9,10,14,15	III
14	1,5,9,10,14	1,4,5,6,9,10,14,15,16	1,5,9,10,14	III
1	4	4,16	4	IV
3	4	4	4	IV
4	4	4,6	4	IV
6	4,6,16	6,16	6,16	IV
15	16	6,16	16	IV
16	6,16	6,16	6,16	IV

4.2 Level Partitions

Level partition. In the present case, the 16 enablers, along with their reachability set, antecedent set, intersection set and levels, are presented in Tables 5 and 6. The level identification process of these enablers is completed in four iterations as shown in Tables 5 and 6.

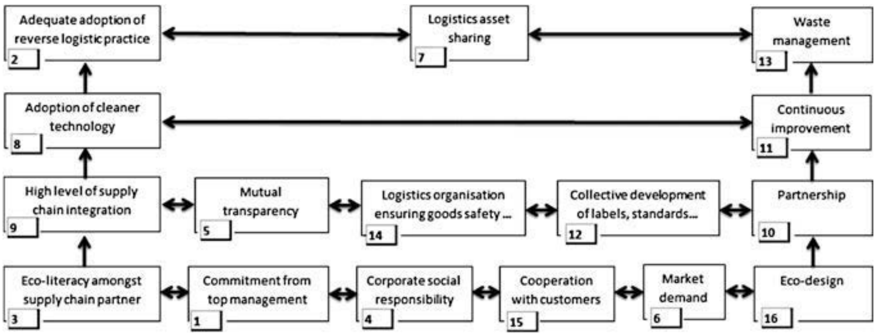

Fig. 2 The ISM based model for enablers of sustainability in a supply chain

4.3 Building the ISM Model

The development of the ISM model. The diagraph for interpretive structural modelling is drawn. Having identified the levels of the elements, the relations between the elements is drawn with the help of an arrow. The level I enablers are in the top level in the hierarchy. The enablers of the same level are kept on the same level of hierarchy. The diagraphs give information about the hierarchy between the elements of enablers for the successful implementation of sustainability in the Supply Chain (see Fig. 2).

The most important enablers in this case are: 'Eco-literacy amongst supply chain partners', 'Commitment from top management', 'Corporate social responsibility', 'Cooperation with customers including environmental requirements', 'Market demand' and 'Eco-design'. Enablers are the base of ISM hierarchy. 'Market demand' (enabler 6) leads to 'Eco-design' (enabler 16) and 'Cooperation with customers including environmental requirements' (enabler 15). 'Eco-literacy amongst supply chain partners' (enabler 3) and 'Commitment from top management' (enabler 1) leads to more 'Corporate social responsibility' (enabler 4).

4.4 Classification of Enablers: MICMAC Analysis

The purpose of Cross-Impact Matrix Multiplication Applied to the Classification analysis (MICMAC) is to analyse the drive power and dependence power of enablers (Mandal and Deskmukh 1994). This is done to identify the key enablers that drive the system in various categories. The variables are classified into four clusters (see Fig. 3).

In the present case, they have been classified into four categories as follows:

- The first cluster consists of autonomous variables (*Autonomous enablers*). These enablers have a weak drive power and weak dependence. They are relatively

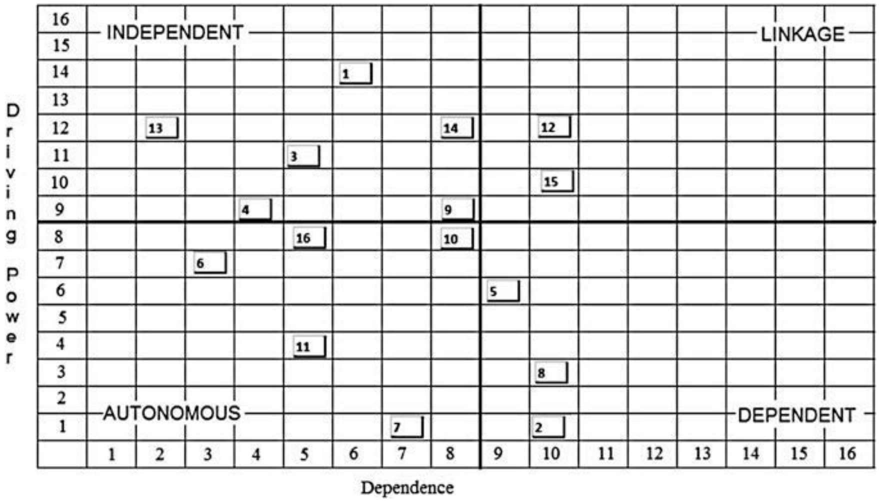

Fig. 3 Clusters of enablers in the implementation of sustainability in the supply chain

disconnected from the system, with which they have few links, which may be very strong.

- The second cluster consists of the dependent variable (*Linkage enablers*). These have strong drive power as well as strong dependence. They are also unstable. Any action on them will have an effect on others and also a feedback effect on themselves.
- The third cluster has the linkage variables (*Dependent enablers*). This category includes those enablers which have a weak drive power but strong dependence power.
- The fourth cluster includes the independent variables (*Independent enablers*). These have a strong drive power but a weak dependence power. It is generally observed that an enabler with a very strong drive power, called the 'key enabler' falls into the category of independent or linkage enablers.

The driver power and dependence of each of these enablers is constructed as shown in Fig. 3 (The driver power-dependence Matrix).

4.5 *Discussion*

In this research, an ISM-based model has been developed to analyse the interactions among different enablers. The main objective of this research is to analyse the effectiveness of various enablers which help in the implementation of sustainability in the Supply Chain in any industry. The methodology proposed here identifies the hierarchy of actions to be taken for handling different enablers' ability to implement sustainability in the Supply Chain. These enablers need to be use for success in the Supply Chain.

The managers can gain insight into these enablers and understand their relative importance and interdependencies. The driver dependence diagram gives some valuable insight about the relative importance and interdependencies among the sustainability in the Supply Chain enablers.

Some of the important implications emerging from this study are as follows:

Figure 3 shows that in Autonomous enablers are five enablers: 'Market demand' (enabler 6), 'Logistics asset sharing' (enabler 7), 'Partnership' (enabler 10), 'Continuous improvement' (enabler 11), 'Eco-design' (enabler 16). Autonomous enablers are weak drivers and weak dependents and do not have much influence on the system.

Two enablers are Linkage enablers. Linkage enablers are 'Collective development of labels, standards, norms, best practices databases, existing guidelines, voluntary agreements, and private sectors initiatives for self-regulation' (enabler 12) and 'Cooperation with customers including environmental requirements' (enabler 15). They have a strong driving power as well as high dependencies. If they are implemented in a proper way they can create a positive environment for the successful implementation of sustainability in the Supply Chain.

Enablers' 'Commitment from top management' (enabler 1), 'Eco-literacy amongst supply chain partner' (enabler 3), 'Corporate social responsibility' (enabler 4), 'Waste management' (enabler 13) and 'Logistics organisation ensuring goods safety and consumer health' (enabler 14) are Independent enablers. They have a strong driving power and weak dependency on other enablers.

'Adequate adoption of reverse logistic practice' (enabler 2), 'Mutual transparency' (enabler 5) and 'Adoption of cleaner technology' (enabler 8) are Dependent enablers. These enablers are weak drivers but strongly depend on one another. The managers should take special care to handle these enablers.

5 Conclusions

This model proposed for the identification of enablers of sustainability in the Supply Chain can help in deciding the priority to take steps proactively. The results of this research can help in strategic and tactical decisions for a company wanting to create sustainability in the Supply Chain. The main strategic decision relies on 'Eco-literacy amongst supply chain partners', 'Commitment from top management', 'Corporate social responsibility', 'Cooperation with customers including environmental requirements', 'Market demand' and 'Eco-design'. Enablers at the bottom of the ISM-based model are the most important enablers that initiate strategic activities.

The analysis reveals that six enablers 'Commitment from top management', 'Eco-literacy amongst supply chain partners', 'Corporate social responsibility', 'High level of supply chain integration', 'Waste management' and 'Logistics organisation ensuring goods safety and consumer health' are ranked as Independent enablers as they possess the maximum driver power. This implies that these variables are key barriers in the successful implementation of sustainability in the Supply Chain.

The most important among them are ‘Eco-literacy amongst supply chain partners’, ‘Commitment from top management’ and ‘Corporate social responsibility’.

There are a number of enablers affecting the implementation of sustainability in the Supply Chain. In this research, an interpretation of sustainability in the Supply Chain enablers in terms of their driving and dependence power has been carried out. With plain common sense, one can think that by focusing on the enablers 9, 10, 12, 14, 15 are essential components of sustainability in the Supply Chain and should to focus more on these enablers. But the results of research show that enablers 1, 13 have a higher driving power and are considered to be the key enablers.

The ISM-based model provides a very useful understanding of the relationships among the enablers. The present model can be statistically tested with use of structural equation modelling (SEM) which has the ability to test the validity of such models.

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Sustainable Transport System Virus: The Conceptual Process Framework of Problems Identification and Analysis in Distribution System

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Abstract The authors of this chapter proposed their own conceptual process framework of problems occurring in organization of transport processes within distribution systems. The proposed tool is a unique hybrid of well-known solutions, presented in professional literature. This conceptual process framework has been developed and successfully implemented as part of works aimed at facilitating the transportation system in one of the largest market chain operators in Poland. Problem identification and analysis tool of organization of transport processes in distribution companies developed within this project has been called Sustainable Transport System Virus Analysis (STSVA). In this chapter basic assumptions and methodology of the tool developed by the authors have been included.

Keywords Transport system · Co-modality efficient planning · Distribution systems · Sustainable development

1 Introduction

An efficient transportation system, as the core component of distribution system, is one of the key elements of competitive advantage of companies. It should be therefore perceived as a managerial value driver. An effective transport system is a

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driving force for efficient functioning of both the company itself and the supply chain, in which the company is involved. Unfortunately, not all companies may regard their transportation and, consequently, distribution systems as effective. Therefore they put in place long-term corrective measures. Streamlining the transportation system is by definition complex and difficult. It should be noted that introducing changes to logistic processes ought to be consistent with the concept of sustainable development, which allows addressing the company's current needs in such a manner so as not to hinder the fulfilment of the same or potential requirements that may arise. In conducting business activity, this concept implies balancing three planes: economic, ecologic and social. Identification of key problems, which determine the effectiveness of the entire company, is very complex and difficult process due to the heterogeneity and variety of problems in the transportation system.

The aim of the chapter is to present how enterprises can identify and improve their transport processes according to the concept of sustainable development. Such problems can be identified and analyzed with support of the Sustainable Transport System Virus Analysis (STVA) tool. The model discussed in this chapter is a unique hybrid of well-known solutions, presented in professional literature. It has been developed and successfully implemented as part of works aimed at facilitating the transportation system in one of the largest market chain operators in Poland. The company's financial standing was improved through better exploiting the potential of managerial value drivers.

2 Theoretical Background

The first step to be taken in every improvement-oriented action is to understand the business process in question. One of the tools used to understand a business process is mapping, which serves several purposes. Firstly, it ensures good understanding of the process elements—actions, results and participants. Secondly, it helps to define the process scope and to separate it from other processes within company. Thirdly, it stands as a point of reference, against which improvement it is measured (Bozarth and Handfield 2006). Besides process mapping, companies must adopt more formalized procedures to be certain that a problem has been diagnosed correctly. Root cause analysis is a technique which involves brainstorming, intended to identify potential causes of problems in the first place, then collecting data and analyzing it in an organized fashion, narrowing down the area of interest to several root causes. Causal maps are one of the tools for root cause analysis. In operations management literature causal maps are known under many names: Ishikawa (fishbone) diagram, impact wheel analysis, issue trees, strategy maps, risk assessment mapping tools (FMEA) and cause and effect diagrams. Cause and effect maps are often used in business. Input data for causal maps should come from the enterprise, and could be captured through,

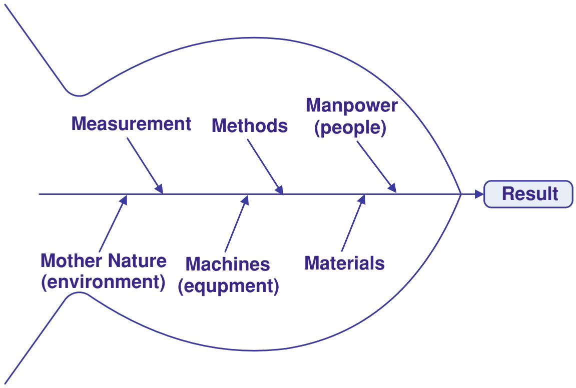

Fig. 1 The Ishikawa diagram

as has been mentioned above, brainstorming technique or personal interviews. Compare in Chmeilewski and Dansereau (1998), Cyplik et al. (2009), Hajdul and Guszczak (2009), Hugos (2003), Kumar (2000), Franceschini and Galetto (2001), Zak (2005).

Tools for Root Cause Analysis

The Ishikawa diagram, also known as the fishbone diagram and root cause analysis, is a simple causal map developed by dr. Kaoru Ishikawa, who first used the technique in the 1960s (Enarsson 1998; Kelley 2000). The basic concept of the Ishikawa diagram is that the basic problem of interest is entered at the right of the diagram, at the "head" of the main "backbone." The possible causes of the problem are drawn as bones off the main backbone (see Fig. 1).

The categories often used as a starting point include materials, machines (equipment), manpower (people), methods, Mother Nature (environment), and measurement (the 6 Ms). Other causes can be selected as needed. Brainstorming is typically done to add possible causes to the main "bones" and more specific causes to the "sub-bones." This subdivision into increasing specificity continues as long as the problem areas can be further subdivided. The maximum practical depth of this tree is usually about four levels. Most quality management authors recommend using brainstorming methods to generate Ishikawa diagrams (Pande and Holpp 2002).

The impact wheel is a simple structured brainstorming approach designed to help managers fully explore the potential consequences of specific events and to identify consequences that they might otherwise fail to anticipate. Although simple, it is a powerful tool for investigating future. The method is widely used by IBM, AT & T and Dayton—Hudson Corporation to identify new markets, products and services, as well as by the US Army to measure alternative tactics and strategies. The group of experts analyse the influence of the introduced change on the other elements of the system, using the three criteria:

- The inferences—The "impacts" of the change;
- The probabilities—The likelihood (probability) for each impact;
- The implications—The cost and benefit of each impact.

The group then focuses on each impact and repeats the process.

Consulting firms often apply a causal mapping tool called an issue tree analysis. The approach helps break down an issue (a problem) into its major components (causes) in order to create the project workplan. Causal mapping is also a key tool for risk assessment (Hodgkinson et al. 1996) and is known by several names such as fault tree analysis (Jetter et al. 2001), event tree analysis (Jetter et al. 2001) and **Failure Mode and Effects Analysis (FMEA)** (Franceschini and Galetto 2001). These maps are used to provide a systematic method for identifying all types of potential failures, their potential causes, and their consequences. These methods are beneficial in the design of a product and a process, in improving understanding of the system, focusing risk mitigation efforts, and identifying root causes of failures. In Poland, Failure Modes and Effects Analysis (FMEA) which is a systematic way of looking at process and product failure modes is the most popular.

A cause and effect diagram is a causal mapping tool for quality improvement and plays a prominent role in quality management programs such as the Six Sigma program (Pande and Holpp 2002). A cause and effect diagram is an extension of the Ishikawa diagram and is not constrained to the "fish" diagram (e.g. it does not require any pre-defined structure and does not use the "M" alliteration to identify potential causes) and uses ovals to represent variables. Many popular books (Pande and Holpp 2002) suggest asking the "five whys," which ask "why" five times in order to uncover the root causes of a problem. Most quality management authors recommend using brainstorming methods to generate cause and effect diagrams (Pande and Holpp 2002).

ABCD methodology has been created to define the importance and range of particular reasons influencing phenomena. The other name is the **Suzuki method**, coming from the name of the originator. ABCD method is implemented according to the following stages:

- Definition of the roots of the problem
- Ordering roots
- Creating and filling in the tables of individual range selection
- Creating and filling in the collective table
- Ranking the roots according to the importance (range)

Table 1 presents the individual table, elaborated in the step 3 of the ABCD method.

The fourth step is presented below. The extreme answers of individual tables are eliminated when filling in the collective table. The corrected sum of activities is calculated then. The measure is the sum of products—the number of significance and range of cause. The next step is to calculate the measure of range. Its volume is defined as a quotient of data in the column "corrected sum of significance" and

Table 1 Individual selection table in the ABCD method

Criteria of evaluation—quality of the order realization		Criteria rank (1—most important, 10—least important)									
Symbol	Name	1	2	3	4	5	6	7	8	9	10
A	Costs of supply										
B	Time of supply										
C	Safety of load										
D	…										

Table 2 Example collective table in the ABCD method

Criteria of evaluation—quality of the order realisation		Criteria rank (1—most important, 10—least important)										Corrected sum of significance	Number of not selected answers	Measure of range	Range
Symbol	Name	1	2	3	4	5	6	7	8	9	10				
A	Costs of supply	2	1	2	1	0	1	0	0	0	0	15	5	3	2
B	Time of supply	2	4	0	0	0	0	0	0	1	0	9	5	1.8	1
C	Safety of load	2	0	1	1	1	0	1	0	1	0	20	5	4	3
D	…														

"number of not selected answers". Finally, the lower measure of range, the more significant is the criteria (Table 2)—compare (Tague 2005).

SWOT analysis is used to perform a strategic evaluation of the company and its processes. It enables reinforcing the strengths of the company, eliminating the weaknesses, making use of the opportunities and eliminating the threats. The name SWOT comes from four English words: Strengths, Weaknesses, Opportunities and Threats. Opportunities—trends in the surroundings that are the incentive for development and reduce the Threats. Additional questions are as followed:

- where are the field of the greatest chances for the company?
- what are the interesting trends in the surroundings of the company?

Opportunities may be stimulated through technology and market, in the micro—as well as macro scale.

Threats—all external factors being the barriers to the company, difficulties, additional costs of activities. The threats are destructive to the development of the organization and the success of the investment. At the same time, they do not enable to make the use of opportunities and strengths. Additional questions are as followed:

- what are the obstacles for the company?
- what are the movements of the market competition?

- what are the technological changes that threaten the company's position?
- changes of requirements for the company, product or service?

Strengths—attributes of the company positively distinguishing it in the environment. Strengths may come from the size of the organization, great share in the market, low unit costs, possessing new technology, quality of production. Additional questions are as followed:

- what are the advantages of the company?
- what is good about the company?

Weaknesses—the consequences of insufficient qualifications and limited resources. They may concern the whole organization, as well as the part of it. Each organization has its weaknesses which, if too numerous, may destroy the company and bring losses instead of profits. Additional questions are as followed:

- what can be improved?
- what is done improperly?
- what should be avoided?
- whether competitive companies observe weaknesses of the company?
- whether competitive companies perform something better than the company?

Theory of Constraints in Root Cause Analysis

Management problems are too numerous and new problems always occur one by one in organizations. Moreover, some apparently intractable problems exist that cannot be solved by past experiences. Theory of Constrains (TOC) elaborated by Goldratt has developed an effective technology for solving problems called the "Thinking Process". This process can be used as diagnosis in medical treatment, to list symptoms and identify "core problems", then to look for a new method of solving problems. Three questions then are discussed: "What to change?" "What to change to?" and "How to change?". The Thinking Process consists of formal analytical tools that are designed to help people answer these three questions. Such technology uses the "Current Reality Tree (CRT)" to diagnose causes or core problems, and the symptoms are called "Undesirable Effects". A common cause is deduced basing on the pattern of observed symptoms. A single symptom can have many causes, but a pattern of different symptoms may have just one plausible cause. Another useful technique of root cause analysis is "Evaporating Cloud"—a specific technique to identify the assumptions underlying the apparent conflict and break the deadlock (Jetter et al. 2001). The above techniques described by Goldratt (1994) have both found their place in the Transport System Virus Analysis (TSVA) proposed by the authors.

The presented set of instruments (Sects. 2.1 and 2.2) is very often used by project leaders to make wide and spontaneous discussion of experts more systematized and ordered. The authors are experienced at moderating meetings concerning identification and problem analysis in different areas of the company's functioning, and according to their practice, each presented solution has its pros and cons. The System Virus Analysis presented below synergizes the selected elements of identification and problem analysis known from literature, combined in a logical sequence.

3 Sustainable Transport System Virus Analysis Methodology

Sustainable Transport System Virus Analysis Methodology is a practical conceptual framework for identifying and analyzing problems faced by a transportation system. The end product of implementing individual stages of this analysis is creating the Transport System Problems Virus. The virus attacks healthy tissue of a transport system and causes their death or transforms them into hybrids that fall short of fulfilling the basic functions they are supposed to fulfil. Infected tissues hamper the functioning of a transport system, which leads to its impaired efficiency. Therefore, an unambiguous identification of the problems virus is a key to its total elimination or, at least, the limitation of its activity, which enhances the effectiveness of transport system. STVA methodology implies passing through the six subsequent stages:

1. Defining the objective of changes;
2. Appointing a team of experts;
3. Determining performance measures;
4. Identifying problems;
5. Statistical analysis of identified problems;
6. Designing the transport system problem virus.

Each of the stages will be elaborated on below.

Defining the Objective of Changes

Problem analysis is most often the first stage of implementing a transport system streamlining project, hence the fundamental role of clear identification of changes in applying STVA. Such decisions fall within the scope of the company Management Board.

Appointing a Team of Experts

A panel of experts should be appointed during direct workshops based on brainstorming techniques with a view to identifying and analyzing problems in a transport system. This panel should include employees directly involved in a transport process, as well as staff from auxiliary areas. The broader the scope of the company functioning covered, the more effective the problem identification process in a transport system. With the members of such a team having competence in all areas of the company's operation, any problems arising on the border of transportation and other functional areas will be for certain identified and analysed. It is possible to divide the panel of experts into smaller groups to run the problems identification workshops based on the brainstorming technique.

Determining Performance Measures

The objectives of process changes should be measurable. It is therefore necessary to evaluate the advantages of improvements intended to enhance the efficiency of a transport system in a selected company. At this stage the main performance measures of a transport system should be selected, which will constitute a measurable effect of improvements to be carried out. A large number of measures may entail certain problems in this case. However, top managers are expected to be able to take right decisions and choose at the maximum 10 major performance measures in a transport system, reflective of the current state of affairs and future changes in the broadest context possible, including sustainable development. Determining performance measures means defining measurable managerial value drivers.

Identifying Problems

Identifying problems of a transport system within STVA implies two stages:

1. Workshops involving a panel of experts, where problems in a transport system are being identified based on the brainstorming technique.
2. Drawing and analyzing maps of processes based on well-known tools for developing such elements.

Based on identified problems, the panel of experts should determine the impact of each diagnosed problem on the objective of the change project and its parameters as defined in the previous stage of the STVA model implementation. It is recommended to apply relative dispersion rate index to unambiguously determine compliance among the experts.

Statistical Analysis of Identified Problems

Statistical analysis of identified problems is a stage at which problems reported at the workshop by the Team of Experts are subject to grouping and preliminary analysis. What is examined here is the impact of defined problems on individual parameters of success, determined within the third stage of the STVA model. Analyses are performed using statistical tools, such as: histograms, bar charts etc. Thus prepared data is utilized in the second stage, which is analyzing the current situation and finding root causes.

Designing the Sustainable Transport System Problem Virus

The aim of this stage is to find root causes underlying the current situation by designing the Sustainable Transport System Problem Virus. In line with the STVA methodology, this task involves examining the material compiled in earlier stages. The virus consists of:

- central part referred to as the nucleus
- internal coating,
- external coating.

External coating has protrusions on its surface, representing the symptoms of problems which appear in the process of production. It has been divided into 3 zones illustrating the aspects of sustainable development of a company (economic, social and environmental). Each of highlighted zones stands up for the symptoms of problems suffered by a company.

Internal coating contains the major problems, manifested by symptoms identified in the external coating. As a single problem may be seen as economic, social and environmental, the authors have decided to introduce an additional measure—problem density (ρ). Maximum problem density is 3, minimum—1 (value 1 means that the identified problem has an adverse impact on the company's functioning in only 1 of 3 aspects of sustainable development; 2 indicates negative influence in 2 out of 3 aspects, and, 3 denotes that all 3 aspects of sustainable development in the company's functioning are adversely affected).

The virus nucleus symbolizes root causes—fundamental problems within the organization. Their elimination will deactivate the entire virus.

Although the members of the problem identification team may seem to have discovered the root cause, their views must be verified before they proceed to design a process streamlining solution. A real data analysis based on the tools such as correlation diagrams, control sheets, Pareto analysis, performance measure analysis and a tool for logical inference tool will allow approval or rejection of the diagnosed root cause (Bozarth and Handfield 2006). A sample Transport System Problem Virus is presented in Fig. 2—compare too (Cyplik and Hadas 2011).

4 Empirical Verification of STVA Tool

The tool for identifying and analyzing problems in a transport system, designed by the authors, has been validated by one of the main Polish market chain operator. Transport system of company which was involved in the validation process is in many aspects a typical representative of companies operating as market chain operators. Both own means of transport as well as external fleet are in used. The main objective of the transport department within this company is to organize effectively and efficiently delivery to the markets. The anticipated effect of the STVA tool was the identification of the key transport system problems in the context of sustainable development. Elimination of identified problems was carried out in the next step. Such a measure was intended to improve the financial condition of the company by better utilization of the potential of managerial value drivers.

Defining the Objective

The main objective of streamlining project in the company under analysis was to design solutions which would enhance the effectiveness of the transport system. Such an improvement requires that the concept of improvement of the transport system's effectiveness be defined in the first place. Therefore, an efficient transport system may be construed as a set comprising the means of transport, point and

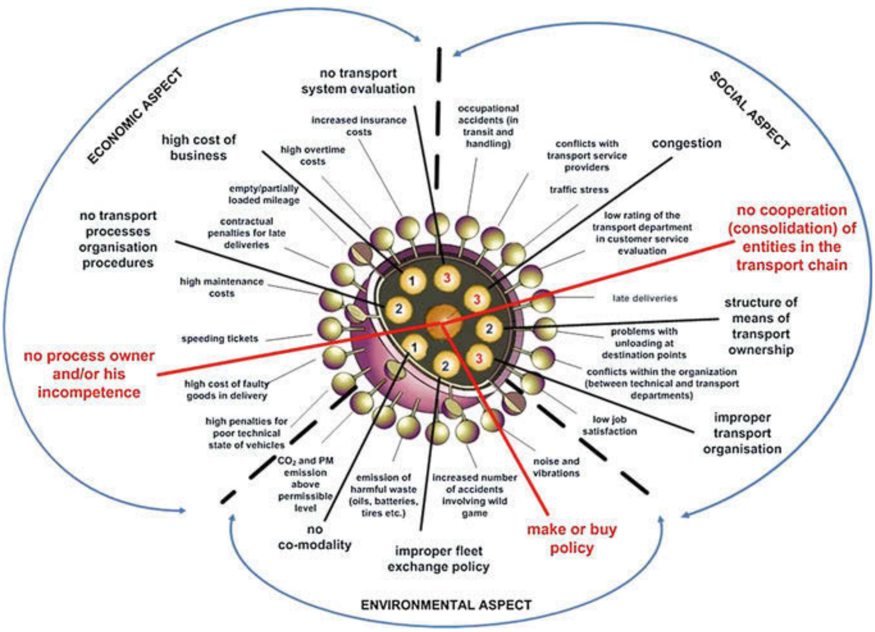

Fig. 2 Sustainable transport system problems virus of the company under analysis

linear transport infrastructure, people, as well as principles of its functioning. Those rules govern the moving of people and goods from points of departure (dispatch), through potential reloading points right to end points (receipt). The rules of functioning are the rules of movement organisation. The main objective of transport system functioning is an efficient organisation of transport processes by effective use of means of transport independently and in combination, which will result in an optimal and sustainable use of resources (Hajdul and Guszczak 2009); (Hajdul and Cyplik 2009). Such an approach is in compliance with the European Union transport policy promoting co-modality.

Appointing a Team of Experts

A panel of experts (Project Team) has been appointed to analyze and identify problems in the transport system of the analyzed company at direct workshops, which were carried out based on brainstorming techniques. The Project Team has been divided into three groups:

- **Steering Committee**—the company's Management Board,
- **Core Team**—20 key employees of the company, in charge of the main and auxiliary processes in the field of manufacturing, including, among others: Transport Manager, Service Manager, Production Manager, Sales Manager, Purchasing Department Manager etc.

- **Support Team**—Eight employees in charge of auxiliary processes, including: Chief Accountant, HR Manager, Stock Department employee, Head of Environmental Protection Management and Safety at Work Team etc.

Each of the groups described above had an equal share of influence on the final result of the works. The division into smaller groups was related to a more effective conduct of workshops based upon brainstorming technique. The full approval of decisions made by other groups falls within the competence of the Steering Committee. Such a cross-section of employees, covering all areas of the company's operations, will ensure the identification and analysis of problems in the transport system in a broad context of the impact they exert on the overall performance of the company.

Determining Performance Measures

The main criterion used in the process of indicator selection was the verification of a co-modal approach in the transport processes organization, which implies an efficient use of various means of transport, independently and in combination, for the purpose of optimum and sustainable exploitation of resources. The word optimum should be understood on both economic and service level, as well as with regard to social and environmental concerns. Among others, there are financial measures, safety at work measures, innovation measures, customer service and environmental measures. The group consist of the following indicators:

- LF—Load factor—the percentage of the load of a trailer as regards the weight and volume
- TCP—Transport cost of single pallet—the cost of transport of a single pallet as per 1 km/month
- TCVD—Transport cost in value of delivery—share of costs of transport in the value of transported goods
- IFGD—Indicator of Faulty Goods In Delivery—percentage of faulty items of goods against the overall volume of supplies within a given period of time
- AFUT—Average Fuel Used per Truck—presents the average use of fuel per truck within a given period of time
- WToT—Worktime of single trailer—level of the trailer maximum time of usage within a given period of time
- RTSP—Reliability of Transport Service Provider—defines the number of properly realized orders by the external carrier to the total number of all orders of the carrier within a given period of time
- IoI—Indicator of Introduction—describes effectiveness of a company within the implementation area. It is understood as the percentage of approved streamlining implementations per a time unit.
- IHSW—Indicator of Health and Safety at work - shows the percentage of persons who suffered an accident on the premises of the company in the last quarter of the year.

Table 3 Problem statistics

	LF	TCP	TCVD	IFGD	AFUT	WToT	RTSP	IoI	IHSW	Total
VH	19	18	8	9	1	17	2	2	3	79
Hi	45	23	54	14	1	45	2	9	4	197
Me	1	3	12	5	0	9	1	4	3	48
Lo	0	0	1	1	0	0	0	0	1	3
Total	75	44	75	29	2	71	5	15	11	327[a]

[a] The total number of problems presented in the table above does reflect the actual number of problems identified in the course of the workshops. 176 problems were identified. The number in the table reflects the fact that problems may influence more than one measure

Identifying Problems

A list o problem which occurs in the transport system was defined during workshops at which brainstorming techniques were put to use. In the course of these workshops the Project Team identified as many as 176 problems. For each of them the degree of severity was measured, indicative of the impact they had on the fulfilment of the project objectives (selected from four options: very high—VH, high—Hi, medium—Me, low—Lo) according to the measures—compare Table 1. Identified problems covered all the areas of the company's operations, which was due to the right selection of employees for the Team of Experts. The conformity among the experts was defined by means of the relative dispersion measure.

Statistical Analysis of Identified Problems

All the problems reported in the course of workshops were subject to a more detailed analysis. Table 3 presents identified problems along with the differences in their impact on the measures (LF, TCP, TCVD, IFGD, AFUT, WToT, RTSP, IoI, IHSW) and the category (severity) they were ascribed.

It follows from the table above that problems in the Important category (60%) constitute the largest group. The second largest group involves problems classified as Very Important (24%). Other problems constitute only 16%. Thus, it is evident that the classic Pareto principle was applied—approximately 20% of all the problems were regarded as very important. According to the estimates, solving these problems will enable the realization of 80% of assumed effects.

5 Designing Sustainable Transport System Problem Virus of the Company

The conclusions drawn in earlier stages were the basis for designing the "Sustainable Transport System Problems Virus" of the analysed company in compliance with presented in this chapter methodology.

The main goal the company pursues is to sell goods at a profit. The task of the transport system is to support this goal as rationally as possible. Nevertheless, the analysis makes it clear that the company faces a wide range of management-related problems. The most important are the flow of information, the division of competences (capacity to make decisions) and an overall model of planning and organizing transport processes. Another problem is the ownership structure of vehicles—the company uses own and rented fleet without regard to basic efficiency analyses of undertaken activities. All described problems translate into high costs of logistics organization processes and, consequently, reduce the company's final profit. The need to introduce changes in the company is hence evident, to begin with implementing a model of transport processes organization, precisely defining the scope of responsibilities and the manner of task execution. At present the analysed company fails to learn from its mistakes. Errors are multiple and recurrent (a track record of irregularities). The density (ρ) of major problems identified in the course of the analysis supports the assumption that some problems may be perceived as important from the point of view of all 3 aspects of sustainable development. They involve the lack of transport system assessment as well as congestion and improper organization of transport. Performance measure analysis was also conducted to verify the idea behind the designed virus. As many as 40 indicators were analysed, which described economic, technical, social and environmental aspects of transport system (including TCP, TCVD, IFGD, AFUT, WToT, RTSP, IoI, IHSW measures described as performance measures). Less than 50% out of examined 19 indicators failed to meet the objectives set for them (including 6 out of 8 performance measures). The results of conducted analysis demonstrated that the virus was designed correctly.

6 Conclusions and Further Research

The company's situation can be remedied by returning to long-established, yet still up-to-date principles of good practice—corporate order. The employment of praxeology practices in management will allow the company to enhance the efficiency of its processes and, simultaneously, understand the implications of successes and failures of individual actions. Destroying the virus responsible for the ineffectiveness of the transport system depends on destroying the reasons constituting its core—root causes. They are the following:

- Wrong "make or buy" policy,
- No process owner and/or his incompetence,
- No cooperation in consolidation.

Transport system streamlining processes should be mainly targeted at these three root causes. It will enable the elimination of the company's major problems:

- No transport processes organization
- Defining the proper structure of means of transport ownership

- Inefficient transport organisation (route planning)
- No transport system evaluation
- No rational fleet exchange policy

And, consequently, the symptoms of problems will disappear as well.

Developing the Tool for Analysis

The classic quality management tools are focused on the **impact** given factors exert or on **cause and effect relations** between them. The authors, drawing on their own research conducted in business conditions, observed that seeking a solution to a given problem may provoke many conflicts. These conflicts expose the lack of integrity of implemented functions on both horizontal, concerning various departments, and vertical plane, in the employee-supervisor relationship. These conflicts hinder further work, being a direct **cause of failure** of the process of changes in the management system. To mitigate those conflicts, and to show that they are caused by a specific "virus", which, by spreading all over the organization, destroys its operational culture, the authors put forward the above mentioned **tool for analysing and presenting results**. As regards analytical functions, the tool's objective is to select symptoms and causes and to establish their hierarchy—source and generic.

At the utility level of the conducted research the chief result is, besides the successful implementation of model in a market economy, the development of methodology supporting managerial decisions related to identifying and analysing problems in the transport system. Attempts at implementing the tool met with favourable reception in companies. Target group makes greater effort on eliminating the diagnosed virus instead of shifting blame for the current state of affairs.

Further Research

The authors of this chapter find it necessary to proceed with the works on improving the STVA within the following areas:

1. Improving the workshops based on brainstorming techniques for a better identification of key problems of transport systems in analysed companies,
2. Improving statistical tool applied for analysing identified problems,
3. Defining the next stage of STVA—developing methodology of selection and establishing the sequence of solutions to implement with a view to eliminating the virus of transport system in analysed enterprises.

The last area has been particularly challenging for the authors of this chapter. It is developing the methodology of selection and establishing the sequence of solutions to be implemented with a view to eliminating the transport system virus. Analysed company is currently conducting implementation works intended to streamline the transport system as a consequence of applying the STVA tool.

Based on the research into the management of logistics, manufacturing and transport, the authors noticed that generic causes, affecting the virus impact and form, may vary in intensity. A specific "density of generic causes" defines to some extent the virus type, which is why it should be subject to further research.

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Internet Support of a Reverse Logistics

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Abstract The chapter concerns Polish Internet market of waste material exchanges. The authors pay attention to issues connected with B2B market, electronic exchanges, and reverse logistics. Connecting those three areas is a starting point to a study which consists in an identification of national waste material exchanges at the first stage, then their estimation according to 10 criteria, and determining strengths and weaknesses of the Internet waste material exchanges. These criteria include such areas like price lists, regulations, a level of a technical backup, multilingualism, and a possibility to use a trial version. According to accepted criteria, was made the characteristics of the Polish Internet waste material exchanges.

Keywords Reverse logistics · Internet waste exchanges · E-commerce

1 Introduction

Development of information and communication technologies has caused changes in all the areas of contemporary economy. In the area of waste material management, a breakthrough is appearing of waste material exchanges caused by the Internet development. The waste material exchanges help to fulfil higher legal requirements connected with a correct waste material management in an effective way. In the following chapter the authors focus on introducing general rules of

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managing the waste material that function in the European Union area. Apart from legal aspects of waste material management, the aspects connected with reverse logistics issues are also discussed. Moreover, a fact of increasing the number of waste in Poland together with economic development measured by Gross Domestic Product (GDP) index is showed on the basis of official statistical data published by Polish public institutions. The most important purpose of the chapter is presenting the authors own studies concerning waste material exchanges functioning. The accepted research method in the mentioned studies is an analysis of the Internet waste material exchanges existing in Poland. Elements taken into consideration during the analysis are

- acceptability of exchanges' webpages considering foreign languages,
- a main function of the exchange,
- target customers of the exchange,
- a way of starting using the exchange,
- announcements available on the exchanges' webpages,
- additional information available on the exchanges' webpages,
- additional services offered on the exchanges' webpages,
- a price list,
- technical backup for users,
- accessibility to a trial version.

Effects of the analysis, concerning electronic waste material exchanges functioning on the Polish market, are indicating the strengths and weaknesses of this sector of the economy and pointing out its potential areas of development.

2 Theoretical Aspects of Waste Material Economy

The analysis of issues connected with waste material management must include a broad spectrum of problems and a holistic approach to solving these problems. Creating solutions in this scope of waste material economy must also contain apart from technical and administrative aspects the issues of a broadly considered economic effectiveness and a subject matter of legal regulations in this range (Golińska 2009; Ingebrigtsen and Jakobsen 2007). Achieving this postulate is possible only after accepting theoretical axioms concerning environmental systems functioning. The examples of such axioms, which constitute the basis to detailed solutions in the range of environmental protection in general, and a waste material economy in particular, can be reduced to the following conclusions, namely (Szołtysek 2009 pp. 47–48):

- everything is connected in an interdependence network between flora and fauna, and physical and chemical environment; such a network is in a balance through implementing an ability to restore ecological homeostasis,

- matter is indestructible and only transforms itself in a cycle of natural environment transformation where living organisms and their products are used; not understanding of this assumption occurs in an excessive accumulation of waste which cannot be biologically processed and in a result it leads to an environmental hazard and a human's health hazard,
- nature chose an optimum set of chemical substances needed to its functioning when evolution experiments had taken place and every introduction of a new artificial substance upsets a delicate ecosystems' balance causing devastation in natural environment,
- in environment there is nothing for free and everything should be paid for, in other words, in appropriate time the consequences for not abiding by the environmental rights are to be taken. People frequently do not realise this fact due to a long period of time in which negative phenomena appear that upset a natural balance.

Considering the rules presented above, the most important issue in waste material management area is minimising the number of substances that cannot be biologically processed and which are stored in environment. This can be done through maximising their re-use. At the macro-economical level, it is essential to create appropriate legal and economic regulations in order to fulfil such a postulate.

In the European Union countries, the most important legal regulation in the scope of waste material economy is undoubtedly Directive 94/62/EEC which concerns all the packaging and packaging waste. A major purpose of the mentioned Directive is a reasonable packaging and waste economy and simultaneously fulfilling a supreme rule of the European Union functioning which is a rule of free competition and mutual commercial intercourse between member countries of EEA (European Economic Area).

Directive 94/62/EEC regulates the following issues in detail:

- preventing the packaging waste to arise,
- promoting reverse packaging intended for multiple rotation,
- recovering resources or energy from packaging waste,
- secondary processing of recovered materials.

Additionally, Directive 94/62/EEC introduces minimal volume indexes of waste recovery. Those indexes must be achieved by all the members of the European Union. Therefore, it was assumed that:

- there should be achieved minimum 50% of packaging waste recovery after 5 years from establishing the Directive.
- there should be recycled minimum 25% of materials contained in packaging waste after 5 years from establishing the Directive. However, lower levels of waste recycling were established for such countries as Greece, Ireland, and Portugal. The reason why such a decision was taken was a specific geographical location of these countries.

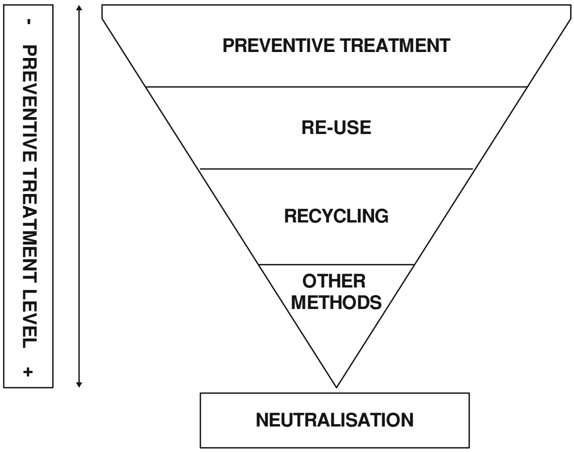

Fig. 1 Hierarchy of measures reducing the number of produced waste. *Source* (Kardaś 2010, p. 6)

Simultaneously, an emphasis was put on a promoted use of secondary materials to producing the packaging and other goods. Moreover, a recommendation was introduced to develop research and work out techniques of ecological assessment for packaging and materials.

Another important EU law regulation in the area of waste material economy is Directive from 19 November 2008 concerning waste also called frame directive. This Directive determines major directions of EU activity in the scope of waste management. It introduces a notion of recycling as any recovery process within which waste materials are secondary processed into products, materials or substances used with an original aim or other aims. Moreover, it also defines a notion of a recovery as a process which its main result is that waste will be useful due to the fact that they will replace other materials which otherwise would fulfil a particular function. An important recommendation in the mentioned Directive is also to introduce an alignment of measures' importance and the measures reduce the number of produced waste. The mentioned alignment in an illustrative way is presented in detail in Fig. 1.

The natural consequence of the idea of sustainable development is striving for benefiting from reverse logistics and closed-loop supply chain, as these approaches allow benefiting from secondary materials and improving efficiency of company's performance (Krikke et al. 2001, 2004).

A supplement to the Directives described above is Directive 99/31/WE concerning the waste storing which regulates the issues of location, build, and exploitation of waste storage yards.

A developed European Union's legal system in the scope of waste management is a result of a broader rule accepted by the EU, namely a rule of a balanced economic development. This rule assumes that a natural environment should not be treated instrumentally as a mean to reach economic subjects' goals. Still, economic subjects are a part of the environment and they should disturb a delicate balance of complicated biological systems to a minimum level.

Table 1 Prognoses of the number of produced waste in 2011–2022

	Itemisation	Mass of produced municipal waste (in thousands Mg), in the following years:					
		2011	2013	2014	2017	2020	2022
1	Paper and cardboard	1592.8	1653.5	1682.8	1795.7	1889.4	1949.2
2	Glass	1249.8	1285.5	1304.5	1358.9	1412.7	1454.5
3	Metals	285.0	287.7	288.8	290.7	288.5	286.5
4	Plastic materials	1606.7	1652.0	1690.5	1766.2	1885.7	1973.3
	Together	4734.3	4878.7	4966.6	5211.5	5476.3	5663.5

Source National Plan of Waste Economy 2010

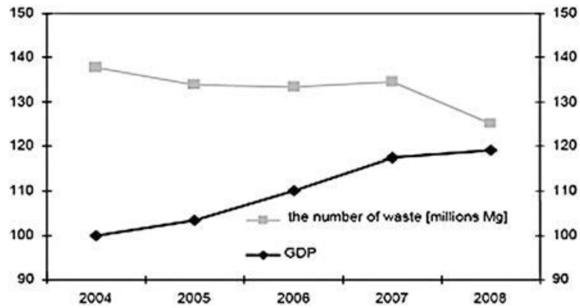

Fig. 2 A correlation between GDP and the number of produced waste in Poland. *Source* National Plan of Waste Economy 2010

3 The Prognoses of the Number of Waste in Poland

According to National Plan of Waste Economy in Poland, the waste are distinguished into three groups, namely

- municipal waste,
- dangerous waste,
- other waste including industrial waste, sewage waste, and packaging waste, however, there was a detailed reference to those types of waste for which significant problems were identified.

For each of those groups prognoses of the number of produced waste in 2011–2022 were elaborated. The most detailed and reliable data concerns municipal waste (see Table 1) which results from their essential influence on the whole waste management system in Poland.

Analysing Table 1 we can conclude that Polish authorities predict a successive growth of municipal waste. Similar tendencies, regardless of less accurate statistical data, can be observable for the other classified groups of waste. A justification for an assumption concerning the number growth can be historical data showing a correlation between economic growth signified by GDP index (Gross Domestic Product index) and the number of produced waste in 2004–2008.

Figure 2 illustrates a quite strong correlation between economic growth and the number of produced waste. Assuming that Poland as a developing country will indicate a positive increment of GDP in the nearest years, a thesis concerning the growth of waste number is legitimate regardless of technological and organisational progress which tends to neutralise the waste. Accepting the rightness of this thesis leads to important conclusions, namely a major and crucial problem in the nearest period of time will be issues of broadly considered eco-logistics, and particularly a subject matter of a reverse logistics.

4 Reverse Logistics

At the beginning of 1970s the awareness of a need to protect natural environment against an excessive exploitation of natural resources and uncontrolled emission of toxic substances and waste has started to develop (Sadowski 2010). Since that moment many countries had introduced a range of legal records which solved current environmental problems and had an influence on developing pro-ecological attitudes in society. Apart from that, a consumption level achieved by a growing number of world's population, which has limited resources and abilities to remove waste, is systematically increasing. This negative trend is connected with growing consumers' intentions to purchase technologically new products. However, developing awareness of non-renewable natural resources causes that the world's economy tends to limit the output of natural resources. Therefore, the use of economical materials and resources from waste materials is becoming more common. Moreover, the awareness of non-renewable resources existence causes the growth of interest for recycling, regenerating and multiple usages.

However, the issues concerning reuse of waste emerged in connection with administration processes and human existences have been observable since many years. According to Sadowski, a phenomenon of waste stream concentration in the industrial sector had become the basis for the first solutions in a waste management sphere. In a consequence, waste management has started to become an essential area of an economic activity which is responsible for limiting the results of interaction of the whole societies and economic sectors on natural environment (Sadowski 2010).

Despite that, previous ways and methods of waste management in local, national, regional, and world aspects characterise small efficiency and small effectiveness of achieved ecological goals (Sadowski 2010, p. 62). A complex problem of waste management, as Sadowski indicates, exacts to use interdisciplinary solutions in this sphere. Such an approach had caused that logistics specialists started to pay attention to a waste management problem. Placing theoretical rules and solutions from logistics to solve the problems connected with waste materials resulted in emerging and popularising the concept of a reverse logistics.

The authors of the chapter accept the notion of the reverse logistics following Sadowski. Thus, reverse logistics is an integrated system of shaping and controlling processes of waste materials flow which is oriented on recreating an

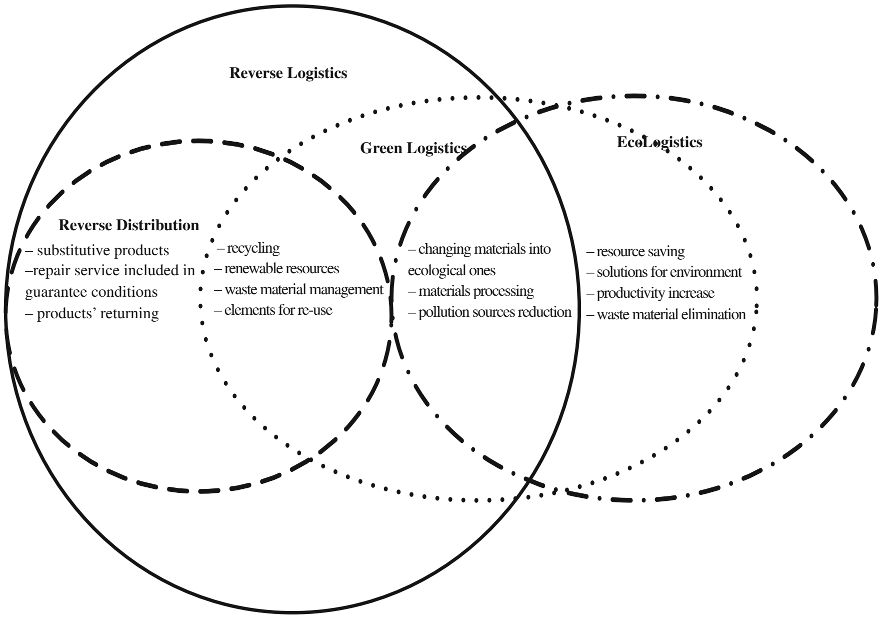

Fig. 3 Areas of reverse logistics (adopted from Sadowski 2010, p. 63)

economic value and minimising an interaction on natural environment in the economy and its links (Sadowski 2010). In a consequence, the notion includes a reference to a range of flows from reversed logistics spheres as well as a reverse distribution, eco-logistics, and a green logistics. The spectrum of problematic areas in logistics is presented in Fig. 3.

Reverse logistics discipline has undergone an increasing development in the last 20 years (Carrasco–Gallego et al. 2011, p. 569). The main focus of the discipline has been centred on two aspects:

- The organization of reverse material flows in supply chain networks (returnable packaging, commercial returns, remanufacturing) and the integration of the reverse flow and the forward flow in the so-called closed loop supply chain (Guide et al. 2003, pp. 3–6),
- The management of products in end-of-life phase (waste management, recycling), mainly from an environmental perspective (Certer and Ellram 1998, pp. 85–102).

5 Internet Exchanges

Electronic market development has caused that enterprises, which function in a virtual environment, take up intensive cooperation. Types of relations appearing within the mentioned cooperation are presented in Fig. 4.

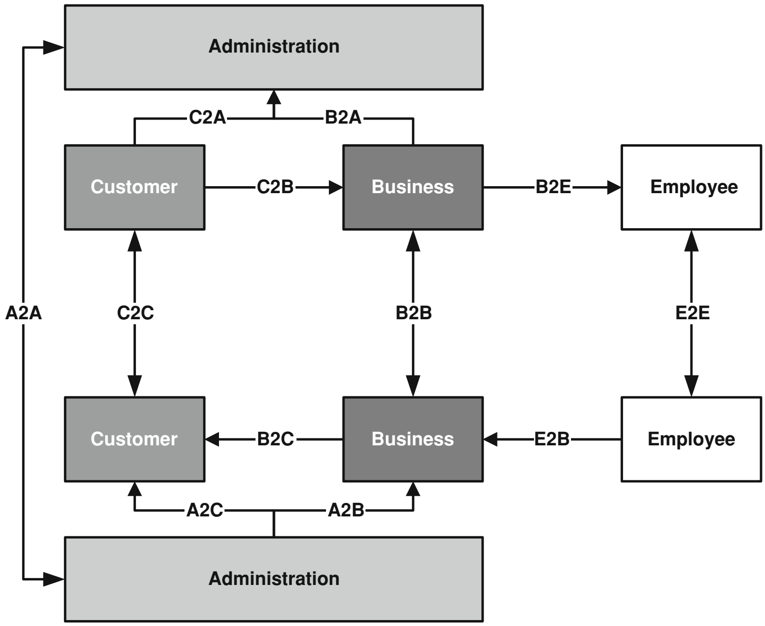

Fig. 4 Types of relations in electronic economy. *Source* Based on Olszak and Ziemba 2007, p. 43

In the simplest form, B2B market is a place where information is exchanged between enterprises through the medium of the Internet which creates a value by ensuring the access to specialist contents and information and aggregates sides of potential transactions (purchasing and selling) in a particular place in the net, in other words, on a market's website (Roskill and Cocorift 2000, p. 4). Therefore, we can also say that eMP (*electronic Market Place*) is a specialised website on which market's participants i.e. sellers and buyers meet with the purpose of concluding commercial transactions. A different notion uses the fact that every B2B transaction contains three stages, namely:

1. collecting information,
2. negotiations,
3. realisation (Salomn 2002).

On this basis, B2B market can be defined as a subject functioning by means of the Internet which supports all the transaction's stages including setting a price of a product or a service (Wielki 2000, p. 98). However, contemporary electronic markets are something more than just a place in which transactions are concluded. An offered functionality on those markets should be regarded in broader perspectives rather than just the opportunity to conclude transactions as it offers additional services of various kinds for example transport, financial and logistics services etc.

Relations of B2B type take place between subjects such as enterprises, institutions, foundations etc. They can relate to many areas of economic activity for example an order realisation at suppliers, selling of goods, products or services to sales representatives or traders, orders directed by a company to a bank which provides its services to this company, a wholesale transaction between enterprises on a commodity exchange etc. (Olszak and Ziemba 2007, p. 42). An electronic market of B2B type integrates buyers and suppliers in one place in the net. Depending on a degree of development, apart from evident economic benefits for enterprises which use this kind of cooperation, it guarantees safety of conducted commercial transactions via the Internet and additionally it provides financial and logistics services.

The word “exchange” (comes from a German word “Glide” which means in English feature, characteristic or attribute) is a notion from a sphere of economics and means a constant, regular meeting of people who purchase, sell or act as intermediary in those transactions following specified rules. These rules make it possible for the people to conclude transactions without the necessity of physical presence of goods. Prices on the exchange are set mainly on the basis of current supply and demand on a given product. Obviously, similar rules are obligatory on a services exchange including forwarding exchanges. At present technological conditions, the meeting of people is possible to happen by the means of electronic platform.

Electronic exchanges, considering the number of purchasers and suppliers, can be divided into categories:

- many suppliers and many purchasers,
- one supplier and many purchasers,
- many suppliers and one purchaser (Adamczewski 2001, pp. 107–108).

Generally, two types of electronic exchanges are distinguished, namely general (horizontal) and trade (vertical) (Adamczewski 2001, pp. 107–108).

Most of exchanges define in their regulations that they are not responsible for a credibility of companies functioning on a given platform. There are exchanges which check their clients before their registration (Olszak and Ziemba 2007, p. 110). Electronic exchanges are found to be the most complicated models among business models of B2B sector (Modzelewski 2000, p. 15).

At present there are a lot of offers of this type on Polish and European markets. We can differentiate a few basic groups of solutions (Długosz 2009, pp. 53–54):

- **Websites**—which after a user’s logging offer an access to their databases both in the form of browsing the offers and adding own ones; they are the most numerous group of solutions from the scope of electronic exchanges.
- **Off-line databases**. Users, who have the use of application on their computer which is obviously offered by a company that provides such services, have an opportunity to browse through the offers and enter new ones. This application is also used as a communication medium. After connecting with an exchange’s server the data containing offers is sent and a local database is updated.

Table 2 Chosen sites connected with a recovery

Company's name	Company's URL address
Aucnet	Enter only for enterprises
Autodag	www.autodag.com
Bigmachines	www.bigmachines.com
Dell	www.dell.com
E-rma	www.e-rma.com
Ebay	www.ebay.com
Fairmarket	www.fairmarket.com
Finda-a-part	www.finda-a-part.com
Genco	www.genco.com
IBM	www.ibm.com
HP	www.hp.com
Metalsite	www.metalsite.com
Pharmacy returns	www.pharmacyreturns.com
QXL	www.qxl.com
Xerox	www.xerox.com
Re cellular	Enter only for enterprises
Returnlogistics	www.returnlogistics.com
The return exchange	www.thereturnexchange.com
Yantra	www.yantra.com
Viavia	www.viavia.nl

Most often updating only concerns these offers which are in the centre of user's interest.

- **Mailing lists**. When using electronic mail (e-mail), users exchange their offers between one another. A serious disadvantage of such a solution is the fact that unfortunately they receive all the offers that had appeared on a mail server so far which manages this service. Significant for some companies could be the fact that services of this type are usually free.
- **Single-purpose communicators**—they enable a contact in a real time with potential cooperation partners using the concept many-to-many. These are solutions from electronic exchanges group.

6 Internet Aggregator Market in Reverse Logistics

At the very beginning the essence of recovery should be introduced because Internet exchanges i.e. aggregators are connected with recycling to a highest degree. Recovery actions are connected with three concepts of waste materials management systems. Therefore, there can be distinguished:

- close—loop recycling,
- open—loop recycling,
- energy recovery.

Table 3 Identified sites of Internet waste material exchanges

Exchange's name	Exchange's URL address
Giełda Odpadów Maszyn i Urządzeń (*exchange of machinery and appliances waste*)	http://www.gielda.hb.pl
Ogólnopolska Internetowa Giełda Odpadów (*all-polish internet waste material exchange*)	http://www.gielda-odpadow.pl
GARTIJA.PL	http://www.gartija.pl
polskie-odpady.pl Ogólnopolska giełda odpadów (*polish-waste.pl all-polish waste material exchange*)	http://www.polskie-odpady.com.pl
Europejski Portal Odpadów (*European portal of waste material*)	http://www.polskie-dpady.com.pl
RecyklingTrade.com—Giełda Odpadów (*recyclingtrade.com—waste material exchange*)	http://www.recyclingtrade.com

Internet waste materials exchanges constitute a platform of information exchange between buyers and sellers. Referring to this basic function, they contribute to development of recycling materials market.

After "internet wastes market" is type, web pages in which adverts with offered by enterprises are presented and possibilities to give as well (Pruska et al. 2011).

An example of worldwide Internet sites, on which a communication between buyers and sellers concerning recovery takes place, is introduced in Table 2.

In 2011 the authors reviewed Polish Internet sites on which an information exchange connected with recovery takes place. Due to the character of those sites and information available on them, the authors accepted to name them as Internet waste material exchanges. Such a name is also used by the owners of those Internet sites who put a word "exchange" in the name.

On the basis of the mentioned review done in June 2011, the authors identified 6 Internet waste material exchanges. Their names and URL addresses are presented in Table 3.

7 Characteristics of Polish Market of Internet Waste Material Exchanges

After identifying the subjects of a study on the basis of data from Internet websites covered by the study of Internet waste material exchanges, the authors analysed the data following the accepted criteria such as:

1. Availability of exchange's website considering a foreign language or foreign languages.
2. The major function of an exchange.
3. The target audience of an exchange.
4. A method according to which an exchange is started to be used.
5. Announcements' sectors available on the webpage.

6. Additional information on a webpage.
7. Additional services offered on a webpage.
8. A price list.
9. Technical support for a user (available, not available, on what days, at what hours etc.).
10. Availability of a test version.

On the basis of received information, the characteristics of Polish market of Internet waste material exchanges were added. This way it was possible to determine strengths and weaknesses of the mentioned market.

Among market's strengths of Internet waste material exchanges in Poland we can distinguish the following;

1. *The major function of an exchange*. Each of websites of Internet exchange type covered by a study claims that it is a website which constitute a simple instrument of a trade turnover and the instrument makes it possible to exchange trade offers connected with broadly considered waste material and machinery.
2. *The target audience of an exchange.* A half of Internet waste material exchanges being examined in their regulations do not write about limits concerning conditions which are to be fulfilled in order to become a website's participant. In other cases, in the regulations of using the exchange there are records saying that the tool is directed only to economic subjects which produce and receive the waste and holders of the waste or a natural and legal person or administration units that do not possess legal status and which after coming through a registration procedure gain an access to services offered by an exchange. Or on the exchange there can only be economic subjects both producing and receiving the waste and the holders of the waste referring to act of waste material from 27 April 2011.
3. *A method according to which an exchange is started to be used.* In 5 cases out of 6 of all examined exchanges, in order to start using the website it is necessary to fulfil a registration questionnaire available on the webpage in which a company's name, address data, an e-mail, and in one case NIP (*tax identification number*) and REGON (*company's state statistical number*) should be given. Then, an account must be created. Administrators reserve a right to start data authorisation procedure of a potential user. Only in one case, a website administrator does not require creating the account. Then, it should be given a name, an e-mail address, a phone number, a city name, and the waste description, trade conditions etc. must be enclosed.
4. *Announcements' sectors available on the webpage.* Only one among the examined exchanges does not possess sectors according to which we can search for and attach announcements. In four cases, the sectors are divided referring to the waste type for example printing waste sector, metal waste sector, and waste from wood processing industry sector, machinery and appliances. In one website, sectors are divided according to user's type on a sector producing waste, a sector receiving waste, and after that sectors referring to names of Polish counties.

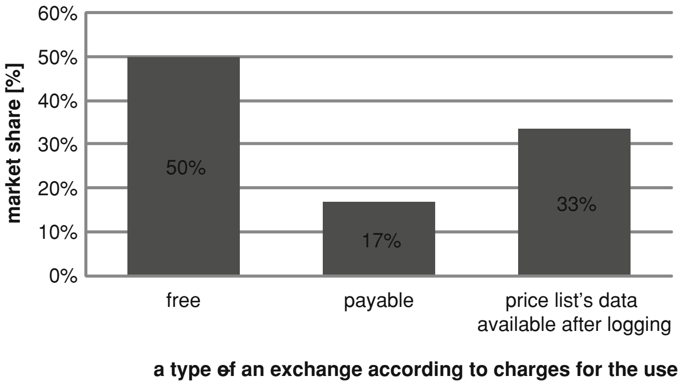

Fig. 5 A structure of a market according to charges for use

5. *Additional information on a webpage.* 50% of websites offer an access to information connected with waste economy such as Polish and European legal acts considering waste material, branch information etc. 33% Internet waste material exchanges covered by the study also run a work exchange and a discussion panel for users on their Internet sites, and 17% run a transport exchange and a probing. In the case of all the websites, the basic data concerning an exchange and clear use regulations are available.
6. *A price list.* A half of the examined exchanges claim in regulations that using websites is free (see Fig. 5). In two cases, the data concerning costs connected with the use is available only after logging or there is a lack of data concerning a price list. The positive fact is that only one website is a payable exchange, and the price covers 3 months of services' use whereas a charge for the next quarter is 20% of a base price.
7. *Availability of a test version.* There is no possibility to use a test version in a case of each of websites covered by a study compared to overwhelming number of exchanges to which there is a free access.

Considering information coming from Internet websites, the weaknesses of Polish market of Internet waste material exchange can be distinguish into

1. *A market's size.* Only six identified Internet sites fulfil the role of aggregator which makes it possible to present offers for purchase and sale of machinery and appliances' waste.
2. *Availability of exchange's website considering a foreign language or foreign languages.* Only two of six Internet sites of waste material exchanges covered by a study (33.33%) are available in a foreign language. One website is available in Polish, English, German, and the second one additionally in French. Undoubtedly, this feature constitutes an obstacle in international exchange.
3. *Technical support for users.* Only in the case of one website, there is a phone help service available for users in weekdays from 8 a.m. to 4 p.m. In two cases

such a phone help can be received by an e-mail or after sending a contact questionnaire. In the other cases this type of help is not mentioned on the websites.

8 Conclusions

Summing up, it can be claimed that Polish market of electronic waste material exchanges is a market at very little scale (only six websites identified). Such a situation is determined by a low popularity of those innovative solutions on a national market. Undoubtedly, an advantage of examined exchanges is the fact that all of them fulfil the basic function, namely they are aggregators of economic subjects connected with waste economy. They constitute a place of “meetings” for subjects producing and buying the waste, therefore, they are an innovative support for a reverse logistics. Considering a growing interest of recovery issues, recycling, and a repeat development, we can expect that an examined market will be gradually getting bigger.

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Part II
Reverse Logistics: Example of Electronic and Electric Equipment Waste Management

Dynamic Recovery Network for WEEE

Paulina Golinska and Arkadiusz Kawa

Abstract The demand for electric and electronic equipment is growing very rapidly. Moreover the life cycles of these products get shorter. It results in a growing amount of waste which needs to be reused or disposed. In many countries producers are obliged to organize a recovery network. Planning of materials flows in recovery network is complex task. In dynamically changing conditions forecasts quickly become outdated. Authors proposed a model based on graph theory and agent technology that provides dynamic configuration of recovery network among pool of cooperating companies. In this chapter are discussed the theoretical backgrounds of research as well as the simulation results.

Keywords Recovery network · WEEE · Recycling · Reverse logistics · Software agents

1 Introduction: Configuration of the Network

Since 2005, member states of the European Union have begun implementing the WEEE Directive, which requires manufacturers to provide the recovery network for used electronic devices. The manufacturers have created a number of alliances which help them to collect and reprocessed WEEE. Still the value of collected

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electric and electronic waste differs dramatically between particular European countries, waving from 3 kg per capita (e.g. Poland) up to over 20 kg per capita annually (e.g. Norway). According to WEEE Forum in 2010, the leading recovery institutions have collected over 31,000 tones of consumer electronics and ICT equipment in Member States. The growing volume of returned product flows requires proper planning tool for dynamic decision making. Dynamic configuration of reverse supply chains within pool of cooperating companies is a challenge. Recovery networks involve collection of used products from the customers, reprocessing and future redistribution to the market. The customers become re-suppliers. Moreover they drive all the reverse flows of materials. It is difficult to match demand and re-supply in the reverse part of the supply chain.

The configuration of a supply chain is the particular arrangement or permutation of the supply network's main elements, including the network structure of the various operations within the supply network and their integrating mechanisms, the flow of materials and information between and within key unit operations, the role, inter-relationships, governance between network partners, and the value structure of the product or service delivered (Srai and Gregory 2008). This definition applies also to dynamic recovery network configuration. In this chapter the emphasis is placed on the particular arrangement or permutation of the network's main elements, including the network structure of the various operations among the cooperating entities. We assume that the relations within pool of cooperating companies can change over time on basis of temporary reprocessing capacity utilization.

In this chapter the emphasis is placed on dynamic arrangements within recovery network in order to provide reverse flow of materials that the best match to the demand. The aim is to minimize time needed for collection and reprocessing of ICT equipments returns.

The chapter's structure is as follows, the brief theoretical background is provided in Sect. 2. Proposed model is presented in Sect. 3. The simulation experiment and its results are discussed in Sect. 4. Final conclusions are stated in Sect. 5.

2 Reverse Logistics and Network Configuration

Reverse flow of materials is supply-driven not demand-driven. It is difficult to control the timing and amount of returns which are pumped into recovery network by products' users. Coordination of the reverse flow is essential in the markets where product returns can be reused and resold to the customers. The returns which appear in recovery network mainly belong to the following groups:

- commercial returns—this category includes: products which do not meet customer expectations; product which are broken/damaged; products which are claimed to be defective or are wrongly delivered. These returns appear mainly in indirect sale (e-commerce, mail) and reach about 25% of all sales, by direct sales this rate is usually below 5%,

Recovery option / Type of returns	Reuse as -is/ Low - touch repair	Remanufacturing	Recycling
Commercial returns			
End-of-use			
End-of-life			
Reusable packing and auxiliary materials			

Fig. 1 Choice of profitable recovery option

- end-of-use returns—this category includes: products which are substituted by technologically upgraded goods, such products are still suitable for use.
- end-of-life returns—this category includes: products which are not working and are usually technically obsolete.
- reusable packing and auxiliary materials—this category includes packing materials and containers which are used to deliver products as well as materials which are necessary for appropriate products usage (e.g. cartridges for printers).

For each type of product returns, there is a most appropriate recovery option (see Fig. 1). The most typical recovery options are: recycling, repair and remanufacturing.

Recycling activities require the decomposition of the product to its components and materials so they can be melted or reprocessed into new materials. Recycling is putting used materials back into the manufacturing chain at a very basic level. “Very simple, low-cost products, broken goods beyond redemption, rapidly evolving designs, and even the bits that have to be replaced during remanufacture and reuse are good candidates for recycling” (Reman 2011). The output of recycling process could be the same products, when the quality is good enough (e.g. steel, automotive plastics) or into new ones in cases where used materials are not meeting the quality standards. Repair includes usually some cosmetics operations like: cleaning, lubricating or other improvements.

Remanufacturing can be defined as an industrial process in which new product is reassembly from an old one and, where necessary, new parts are used to produce fully equivalent and sometimes superior-in performance and expected lifetime to original new product (Lund 1983). Remanufacturing is very different from repair operations, since products are disassembled completely and all parts are returned to like-new conditions.

Commercial returns usually are not used and require only light touch repair like cleaning, relabeling or repacking. It is essential to reintroduce them to the market as quickly as possible. End-of-use returns usually need some technical upgrading in order to be reused efficiently. In case they are still of sufficient quality the preferably recovery option is remanufacturing. If end-of-life products are technologically obsolete and often worn out, then the profitable recovery alternative is usually recycling or dismantling for parts recovery.

Time is important issue in materials management in recovery network, because the longer it takes to retrieve a returned product, the lower the likelihood of economically viable recovery options (Ketzenberg et al. 2006). The design of recovery network is connected with time sensitivity of returns. The marginal value of time is defined as the loss in value per unit of time spent awaiting completion of the recovery process (Blackburn et al. 2004). Responsive recovery network aims to minimize the lead time. Efficient recovery network is designed to achieve the minimal unit cost of reverse logistics operations (including e.g. collection, transport, reprocessing). Responsive reverse supply chains are appropriate for products with high marginal value of time (MVT), whereas efficient reverse supply chains are appropriate for products with low MVT (Blackburn et al. 2004).

The delays in lead times in recovery network might cause situations when a value of returns will erode because of unwanted delays in collection of goods, their delivery and disposition (choice of recovery option). When the emphasis is placed on the cost efficiency, then the returns supply chain should be designed to centralize the disposition activities. When responsiveness is the goal, then a decentralized disposition activities are needed in order to minimize time delays in reprocessing returns. Early diagnosis of product condition maximizes asset recovery by fast-tracking returns on to their ultimate disposition and minimizing the delay cost (Blackburn et al. 2004).

In order to meet this goal the efficient arrangement of materials flow in recovery network is a must.

3 Industry Insights

Computer industry is characterized by: mass production (big materials flow), short life cycles and design for disassembly and reprocessing. The manufacturers of personal electronic and ICT equipment try not only to fulfil the legal obligations but also to gain the benefits of two-way economy. 3R (recycle, reduce, reuse) policy is reflected already in the design phase of products, where manufacturers put a pressure on the durability of the products, easy disassembly, the systematic reduction of the quantities of components and elimination of harmful substances, so that at the end of the initial life cycle as the largest number of elements/materials could be recovered. They design products, packaging and supplies that make efficient use of resources. The extension of the products useful life when possible is achieved through a refurbishing process. In case when particular product cannot be recovered because of technical of economic reasons proper disposal is applied. Another good practice is utilization of useful components and materials from recyclable products. Many ‘end-of-life’ products are still in good working condition and may therefore find useful application. On the other hand, quick depreciation puts this option under significant time pressure (Blackburn et al. 2004).

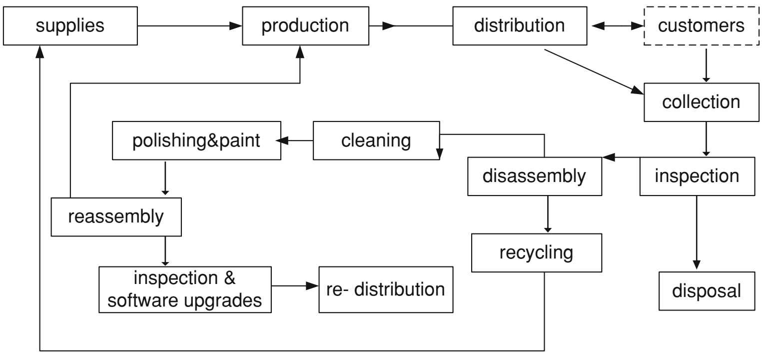

Fig. 2 The materials flow by recovery operations in the computer industry

Environmental friendly supply chain management requires a continuous course of actions in order to decrease the environmental impact of products and technology used by a manufacturer and its pre-chain (suppliers) and post-chain (collection, inspection and reprocessing activities).

Computer companies try to stimulate the reverse material flow by lease programs where return dates are defined. The lease programs are mainly addressed to institutions, individual returns are less coordinated. The return products are refurbished or remanufactured as appropriate, repackaged and resold. Company offers remarketed products for most product types, and follows strict processes to protect user data and to meet environmental requirements. The example of recovery activities is given on Fig. 2. The flow of materials is assigned with arrows.

Nowadays one of the leaders in reprocessing practices is Hewlett-Packard. The company offers for its customers recycling and reuse programs. HP has aimed to recycle 900,000 tonnes of electronic products and supplies by the end of 2010 (since 1987). In reality 884,000 tonnes of electronic products and supplies has been recycled. In year 2010 itself about 30,000 tonnes of electronic equipments were reused or remanufactured. Over 121,000 tones of equipments and supplies (mainly tonners) were subject of material or energy recycling.

HP also uses a network of vendors (service providers) to process, resell and recycle return products. The company issues Global Reuse and Recycling Standards which define conditions and requirements for storing, handling and processing returned equipment in ways that prevent from the leak of harmful substances. Nowadays company has in the pool in recovery network about 500 recycling providers' locations around the world. Institutions providing reuse services for HP products must ensure that those operations occur in on time and secure. The time issue is highlighted by the network configuration. The company tries to limit the storage of goods for recycling or reuse purpose up to 90 days (HP 2011).

Another example of recovery network configuration is IBM. IBM's asset recovery assumes priority on reselling equipment as a whole. The products are sold through IBM's sales network as certified remanufactured equipment. The business partners and brokers are also involved in these operations. For the PC sector, IBM uses a different channel. The products are tested by Global Assets Recovery Services (GARS) and then are auctioned off in large batches to brokers. Overall, IBM is able to resell some 80% of the PCs returned from the business market (Fleischmann et al. 2004). The valuable components are delivered as spare parts to IBM's own service division. In addition, GARS also sells recovered components to external brokers. The remaining equipment is divided into about 50 different material fractions and it sells them to specialized recyclers (Fleischmann et al. 2004).

Xerox's Green World Alliance program provides a collection and reuse/recycling program for the imaging supplies. The Xerox Green World Alliance reuse/recycle more than 2.5 million cartridges and toner containers being returned in 2008. Xerox also processed 800,000 pounds of post consumer waste. For returned cartridges, approximately 60% by volume is remanufactured into replacement cartridges, the other 40% is recycled to recover all the component materials (Xerox 2011). The recovery network uses different channels depending on characteristics of customers. The collection is organized as follows:

- for individual users on the web page of the manufacturer after introducing the type of material and serial number displays a list of the local partners, where the item can be returned free of charge, in boxes there are also special stickers that allow to send by mail (free of charge), items directly to the Recycling Centre, this type of stickers can be also generate on-line on the website of manufacturer,
- for corporate users, there are two variants depending on the quantities of products (toners, inkjet cartridges). A variant of the "Eco-box" is intended for users who return on average between 5 and 30 pieces. They may order by Web page special container that allows the free pickup service by courier. For users who once return over 30 units has been developed a special bulk-returns procedure. Used materials should be stored on pallets in original cartons, which are collected by logistics operator when the pallet weight exceeds 45 kg (100 lb). The user after preparing pallets for shipment must also fill out a special consignment note according to Xerox's specification.

A professional asset recovery program provides a good opportunity to find value in older equipment and to enhance the organization's reputation as an environmental friendly institution. Many organizations won't require enough asset recovery work to justify developing the necessary specialized knowledge and skills. A better solution for them may be asset recovery outsourcing. Professional recovery companies have specialized skills: logistics (inventory control, transport, storage, etc.), data wiping, equipment refurbishment, resale and environmentally responsible recycling.

The structure of the network can be centralized or decentralized. Figure 3 presents the differences between decentralized and centralized returns flow management.

In our approach we have assumed that reverse channels can be dynamically configure from pool of cooperating companies. The goal of the recovery network is to collect and reprocess the products with respect to marginal value of time. The consumer electronics and computer equipments are very time sensitive. So the recovery network should be able to configure dynamically reverse channels within

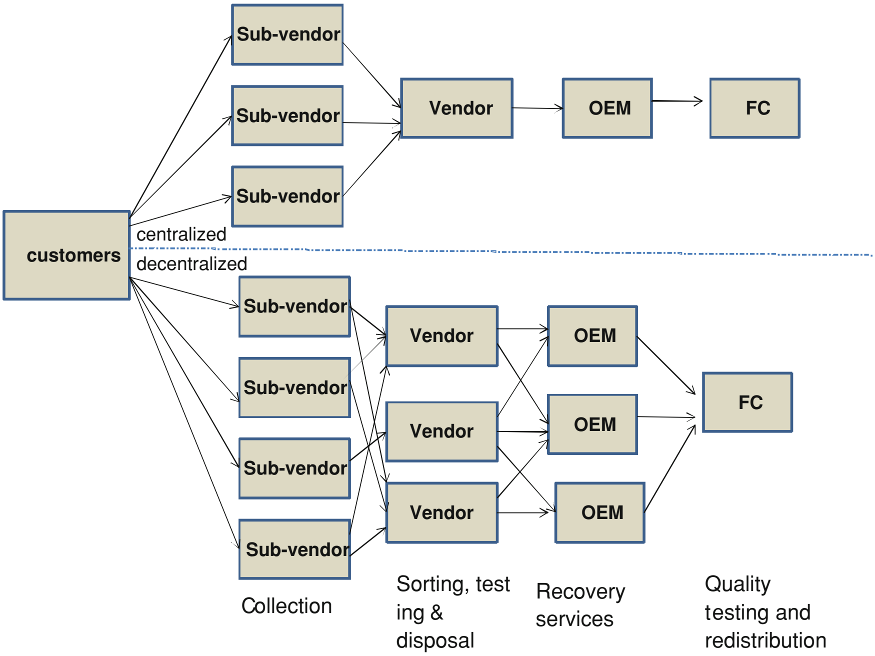

Fig. 3 Reverse channel structure within recovery network

pool of cooperation companies demanding of current availability of collection and reprocessing capacities.

The abbreviation used in Fig. 3 means:

- Flagship Companies (FC) which own such brands as Dell, HP, Apple, Toshiba, Acer ect.,
- Original Equipment Manufacturers (OEM) which assembly/or disassembly the equipment (also are responsible for remanufacturing operations),
- Vendors which are responsible for testing and disposition of reverse flow,
- Subvendors which, are responsible for collecting of equipments and they also might be involved in deliveries of materials for remanufacturing processes.

4 Dynamic Reconfiguration Model

4.1 Previous Work

The configuration process is an arrangement of parts or elements that gives the whole its inherent form. The previous work on recovery network configuration has taken in consideration costs of investments or operational costs in order to find the fixed geographical location of new facilities/points for recovery and product collection (e.g. Beamon and Fernandes 2004). In the dynamic changing economic environment it is more important to focus on the changes in a system (supply chain) than on its total redesign. On account of a huge number of entities which can take part in a supply chain and the complexity of the relationships between them, the configuration process is multipronged and requires particular attention.

A re-configurable network should be a self-adjusting and resilient system reacting to the changes taking place in its individual parts. In practice, planning product renewal many weeks in advance is hardly effective as in dynamically changing conditions forecasts quickly become outdated. That is why the information about the current network situation must be constantly updated and stored in a place accessible to all the interested parties. Parties involved in the cooperation have their own resources, capabilities, tasks, and objectives so there are difficulties in coordination of the constant flows of information, materials, and funds across multiple functional areas both within and between chain members (Golinska 2009).

Thanks to agent technology and graph theory used in logistics it is possible to depart from fixed supply chains, in which enterprises are dependent on one another, and replace them with dynamic configurable supply chains, including constituents, which offer the best conditions of cooperation at a given moment. The proposed model enables to find the quickest path with appropriate capacities in the whole recovery network. Therefore, a FC company being a leader of a recovery network, can satisfy its demand more quickly and facilitate the high marginal value of time (MTV). In computer industry it is crucial to collect and reprocess the returns as soon as possible. Otherwise the product might lose majority of its residual value before entering the recovery operations.

4.2 Graph Theory in Recovery Network

The dynamic recovery network configuration model is based on DyConSC model (Kawa 2009) and extended with the recovery concept. This model enables each entity of the supply chain (forward or reverse) to independently adjust their plans in such a way that they become optimal both within one enterprise and the whole chain.

In the model four tiers of enterprises and one tier (represented by customers) have been distinguished. The first tier is represented by FC followed by OEMs, Vendors and Sub-vendors. For example, OEMs designs and manufactures product for recovery. Vendor provides disposition services of electronic hardware products and materials to or on behalf of FC. It also includes logistics service providers that either provide the processing services directly or through third-party recycling, reuse, or disposal providers. Sub-vendor (any subcontractor or downstream third party) provides disposition services of electronic hardware products and materials to or on behalf of FC’s Vendors. FC provides requirements for recovery. Such an enterprise network comes in the form of a stratified, directed graph consisting of $n$sources (Sub-vendors) and one sink (FC).

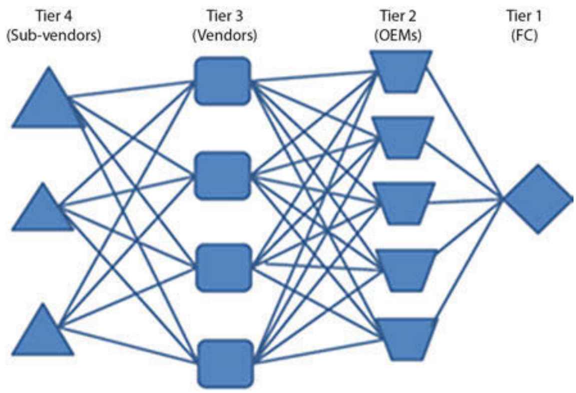

Fig. 4 The simplified model of cooperating companies' pool

In the model goods and information flows take place between consecutive tiers. All goods deliveries are carried out sequentially from the entities of the last tier to the company of the first tier. The information flow is possible thanks to software agents. Autonomous agents representing different enterprises cooperate, co-ordinate and negotiate conditions in order to achieve their common goal.

All deliveries are conducted sequentially so no tier can be omitted. As can be seen in the Fig. 4, a flow (edges) of goods in certain quantities takes place between the entities (nodes) in the recovery network. In such network the cheapest flow with an appropriate capacity is finding (Kawa 2009).

Although it describes the task of linear programming, solving it by general liner programming methods is ineffective due to its network structure. In this case the Busacker-Gowen (BG) algorithm, which is presented in (Deo et al. 1983) is suitable. This method consists in increasing the flow along consecutive paths augmenting as much as their capacity allows. The order of appointing paths depends on their length which, in this case, is determined by unit costs. If the flow has achieved the defined value, computing finishes. Otherwise, the network is modified and next stages are repeated until the flow of the predefined value is accomplished.

To find the cheapest chain from the source to the sink the algorithm of finding the shortest paths must be applied. The model has used the BMEP algorithm (see more in Deo et al. 1983; Kawa 2009).

4.3 Model Assumptions

A given recovery network of enterprises is managed by FC. It controls the whole reprocessing of a product in real time, from the receipt of the returned product through gaining resources necessary for the refurbishment to the delivery of ready (renewed) products to the customer. FC arranges reverse supply chains (materials flow paths) within a given network of cooperating enterprises (potential recovery network). Such chains are created for the needs of a specific transaction evoked by the customer's demand (e.g. via product return in order to carry out the recovery process). FC is also engaged in the optimization of the already existing "reverse supply chains" and the control of their efficient accomplishment so that the customers' expectations related to service quality are met and the lead time from collection to recovery are reduced at the same time. However, the remaining enterprises from the network are directly responsible for the organization and co-ordination of the streams (of goods and information) generated by the suppliers and recipients of the next tier.

The fundamental assumption of the proposed model is form of a stratified, directed graph with individual nodes and edges represented by software agents. A number of additional presumptions essential for correct comprehension and operation of the model have also been distinguished. It is assumed that:

- FC administers a tool which enables to visualize the network composed of all the cooperating companies, the relations between them as well as the review of the whole production process.
- All entities of the individual tiers have the same or very operations,
- FC has access to information about product prices, quality, etc. and supply (reprocessing capacity) offered by all members of the enterprise recovery network.
- Customers' individual return notices are collected and consolidated at specified time intervals (e.g. once a day) and passed on by FC to the right members of the configured reverse supply chain.
- Separate graphs, in which the current connections between enterprises are represented, are built for each collective order.
- A homogeneous Bill of Materials and Disassembly Bill of Materials, which provides information necessary to calculate the size of the returns flows in network. Thanks to that, entities of subsequent tiers know what products, semi-products, subsets, individual elements, raw materials and in what quantities are needed, moreover availability of Disassembly Bill of Materials speeds up the disassembly and inspection operations.
- The realization of the flows between suppliers and recipients may be carried out by the enterprise itself or by an external provider (e.g. a logistics service provider, a courier).
- The costs of sending a flow unit along an edge in a graph are treated as the result of synthetic evaluation of the cooperation between the recipient and the supplier. The software agent of each recipient carries out an evaluation of its direct suppliers, taking into consideration a set of criteria, and then places it on the register server. The information is constantly updated.
- The total of the flows outgoing from a given supplier to their recipients equals reprocessing capacity of the entity in question.

5 Simulation Results

The model was implemented in the NetLogo. It is a programmable modelling platform for simulating which allows giving instructions to a lot of independent agents interacting with one another and performing multiple tasks. The turtles (agents) can be connected to one another by “links” which are also programmable. Collectively, the turtles and links are called agents (Wilensky 2011).

In the simulating model four kinds of “breeds” were distinguished: FC, OEMs, Vendors and Sub-vendors, which allowed to define different behaviours and “agentsets” of those breeds.

The quantity of the potential entities in each tier (except for the 1st tier) is assumed to range from 5 to 200. This number can be increased or decreased with the slider (*nodes-num*). There is only one FC in each network (see Fig. 5). Different FCs from other recovery networks may compete with others.

Two other parameters of this network were distinguished: *chain-demand* and *supply-indicator*. The first one is a demand of the FC which equals the whole supply chain demand by day. The second one is a factor of the supply changeability of particular entities of the network.

The properties of link agents between constituents were chosen randomly as a pair of *cost* and *capacity*. This *cost* is very widely understood in this chapter. It is worth to notice that, generally, sellers give different prices, some of which include other additional costs, but others do not. A lower price is offset by significantly higher acquisition costs such as those of delivery, monitoring, coordination and other administrative tasks (Blackburn et al. 2004). Thus, it is very difficult to compare them with one another. Moreover, the criteria for the choice of the preceding entity may comprise the price, product or service quality, production and delivery time, reliability, customer service, location, etc. In the model *cost* comprised all these components. All of them are quantified and, as a result, can be comparable. We set the cost as a variable between 1.0 and 6.0. In turn, *capacity* is a variable which depends on the aforementioned *supply-indicator*.[1]

Due to the fact that time, or carrying out the recovery on time, to be more precise, is an important parameter, it has been assumed that in a given network there are only such connections between the suppliers of consecutive tiers which can guarantee that the whole operation from the moment of receiving the returned good, through gaining resources, the refurbishment to the product delivery will be completed in 90 days.

In the recovery network we look for such supply chains which meet the requirements and are most effective. In order to find such chains (so the shortest path in the graph), the BG and BMEP algorithms are used. Because the FC demand

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[1] It is established according to the following procedure: c*hain-demand* * *supply-indicator* + *random (chain-demand* * *supply-indicator*). For example, if *chain-demand* = 10000 and *supply-indicator* = 0.1, then *supply* amounts to not less than 1000 and not more than 1999.

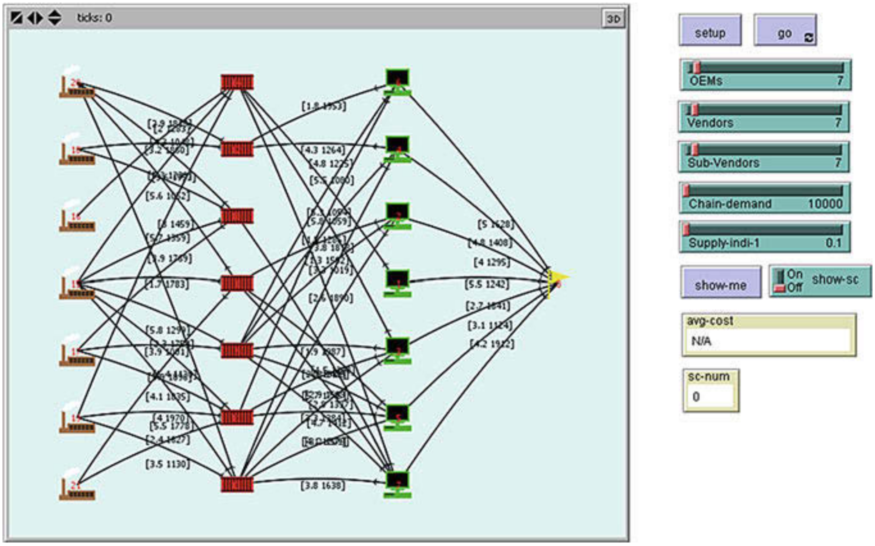


Fig. 5 Screenshot of exemplary recovery network in the NetLogo platform

can be completely or partially satisfied, there can be one or more such chains. Their number depends on the supply and demand changeability.

In order to check the capabilities of recovery supply chain configuration and the effectiveness of the model a lot the simulation experiments were carried out. Their aim was to study how the changes of the node numbers (*nodes-num*) and *supply-indicator* influence the average supply chain numbers (*sc-num*) and the average cost of sending a flow unit along the supply chain (*avg-cost*) in the recovery network. For multiple runs of the model the BehaviorSpace tool was used which allows collecting data in an external file.

For the first group of the simulation experiments it was assumed that *supply-indicator* = 0.1 and *chain-demand* = 10000.[2] The number of entities (*nodes-num*) in a particular tier was changing and consecutively amounted to: 5, 10, 20, 50, 100 and 200 (simultaneously, this number in other tiers was stable and equaled 20). The simulations were run 1,000 times for each case. The findings of the experiment show that as *nodes-num* augments (from 5 to 200), *avg-cost* decreases by 30% on average, but for OEMs the fall is greatest and reaches 44% (see Fig. 5). It can be explained by the following dependency: the more suppliers there are in a given tier, the higher the competitiveness among them is and the lower the prices, the better the conditions of cooperation, etc., become for the final customers. The greatest decline of *avg-cost* is observed when *nodes-num* is increased from 5 to 50

[2] The total annual reuse of equipment in the HP company amounts to approximately 2,5 million of units per year. We divided this number by 250 working days.

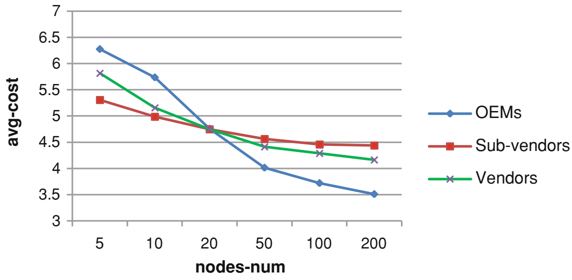


Fig. 6 Influence of enterprises number change in particular tiers on the average cost of sending a flow unit along a supply chain in the network

(by 25% on average). Figure 6 also shows that the greater the nodes-num in the vicinity of the FC (so OEMs, Vendors and Sub-vendors successively), the lower the *avg-cost*.

In the next stage, we changed all *nodes-nums* at the same time and noticed the greatest decrease of *avg-cost* when *nodes-num* rose from 5 to 50 (by 58%), too (see Fig. 7). A further modification of this parameter is also beneficial but not to such a large extent. It must be remembered that a big number of suppliers ensures lower product prices for the recipient, guarantees more safety and reduces the risk of production stoppage, but, on the other hand, causes an increase of the servicing costs of such co-operation (maintenance costs of information systems, control, search of supply sources, negotiation, establishing the co-operation conditions, audit, etc.). One must not forget about the hidden costs related to a limited number of suppliers, either, such as the cost of lost sales caused by a lack of products or about the fact that liberation from a monopolist supplier is time-consuming. In the case of our recovery network a number of suppliers in individual tiers equal to 50 may be recommended.

In the last part of the simulations, the *supply-indicator* variable was shifted from 0.1 to 1.0 (consecutively 0.01, 0.05, 0.1, 0.2, 0.5, 1.0), on the assumption that *nodes-num* is stable and amounts to 20 and *chain-demand* = 10000.[3] The simulations were carried out 1,000 times for each case. The results from the experiment show that *sc-num* falls from 40 to 1 (see Fig. 8). It is worth to notice that augmenting *supply-indicator* ten times (i.e. from 0.01 to 0.1) leads the average supply chain numbers which can satisfy the demand of the FC more quickly to plunge from 40 to 13, i.e. by 68%. As a result of the rise of *supply-indicator* from 0.01 to 1.0, *avg-cost* comes down from 6.4 to 3.7, i.e. by 42% (see Fig. 9). The main conclusion from this part of the simulation experiments is that it is more profitable to cooperate with a trading partner with greater capacities and an ability to offer greater supply. It reduces the number of supply chains.

[3] Here *supply* fluctuates between (100 + random 100) and (10000 + random 10000).

Fig. 7 Influence of enterprises number change simultaneous in all tiers on the average cost of sending a unit along a supply chain in the recovery network

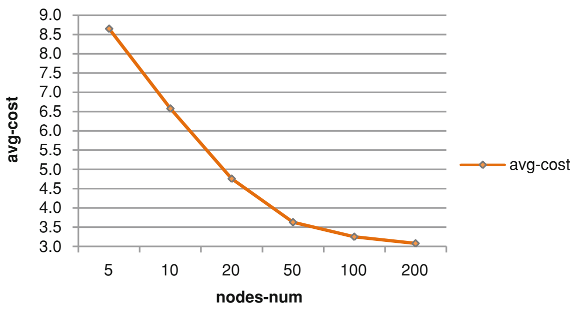


Fig. 8 Influence of the factor of supply changeability on the supply chains number in the recovery network

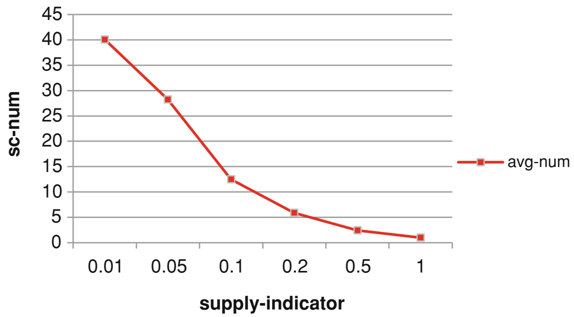
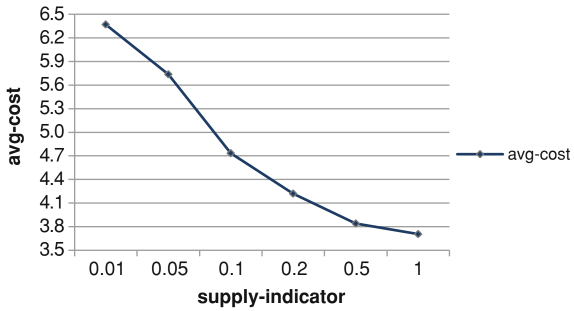


Fig. 9 Influence of the factor of supply changeability on the average cost of sending a flow unit along a supply chain in the recovery network



6 Conclusions

Application of the agent technology and graph theory in logistics allows departing from fixed reverse supply chains, in which enterprises are dependent on one another, and replace them with dynamic configurable supply chains, including constituents, which offer the best conditions of cooperation at a given moment. The presented model enables to find the reverse supply chain within potential recovery network with appropriate reprocessing capacities. Therefore, a company being a supply chain leader can satisfy its demand more quickly and can benefit from high marginal value of time by avoiding unnecessary delays. It helps to choose centralized or decentralized flow of materials according to the current conditions (available collection and reprocessing capacities).

It is noteworthy that the proposed model offers many benefits for the network of enterprises, its participants and the final customer. Some of the most important ones have been distinguished below: goods flow visualization; fast and easy building of closed-loop supply chains; delivery time, stock and cost minimization. The proposed model allows also: quick identification and elimination of bottlenecks, as well as very quick reception of the returned product, in accordance with the customer's expectations, at competitive prices. It gives a possibility to build scenarios and carry out simulations independently.

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Optimizing the Recycling Process of Electronic Appliances

Arantxa Rentería and Esther Alvarez

Abstract Waste coming from disposed electrical and electronic equipment WEEE, also called "e-waste", contains a growing range of electronic appliances of different types and sizes, thus representing an important environmental problem. One of the main problems in e-waste recycling is the lack of collection incentives and recycling infrastructures, as well as the high cost of material collection, handling and processing. A methodology that takes into account technical, economic, legal and environmental issues is proposed in this chapter. The parameters used by this system are the previous expertise of recycling companies, WEEE regulation and economic aspects. The simulation of the proposed solution has been analyzed, together with an economical assessment of the recycling process, in order to show the feasibility of the methodology.

Keywords E-waste · Recycling infrastructure · Waste processing · Electronic appliances · Optimization

1 Introduction

Electrical and electronic equipments cover a wide range of appliances of different types and sizes, ranging from large household appliances to computers, calculators and phones. These appliances are difficult to repair and consumers can find new

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advanced technology products at reasonable prices in the market every year. Consequently, product life cycles of these products are getting shorter. Today's people's behavior for purchasing technology is towards faster, smaller and cheaper appliances, with shorter changing periods of time. As a result, the amount of waste coming from disposed electrical and electronic equipment (also called "e-waste") is causing an important environmental problem (Rahimifard 2008). E-waste in Europe is rising from 3 to 5% annually, 3 times faster than "traditional" waste stream (Hischier et al. 2005).

In the past, many products and components were directly disposed of in landfills rather than recycled. But e-waste contains valuable materials and components, which may be recyclable and reusable, thus saving natural resources. In addition, there are toxic and hazardous substances contained in it which must be identified and separated, else they can originate serious environmental pollution (Streicher-Porte et al. 2005).

Principles of sustainability have emerged in modern societies. The limits to continued growth were addressed at the report of the World Commission on Environment and Development, commonly referred to as the Brundtland Commission (World Commission on Environment and Development 1987). This report is considered to be the foundation of the sustainability development concept during the last two decades (Samson and Singh 2008).

2 Legislation Related to WEEE

The European Union authorities recognized the magnitude of the problem and they approved two directives, the WEEE (Waste from electrical and electronic equipment) and the RoHS (Restriction of the use of hazardous substances in electrical and electronic equipment). Similar initiatives are under way in other countries like Japan, US and China (Khrishna et al. 2011).

These directives demand of EU member states the setting up of collection schemes and infrastructures for separated waste, allowing dealers and users to freely take back the WEEE coming from their stores and private homes.

Firstly, the manufacturers of electrical and electronic appliances are responsible of the management of the waste they generate. In the case of large appliances, producers must collect old appliances when a customer buys a new one. Moreover, producers must re-design their products in order to reduce the use of hazardous materials across the life-cycle of products. Finally, manufacturers must contribute to reduce the volume of waste by facilitating repair, upgrade, reuse, disassembly and recycling. In Fig. 1 a graphical description of the treatment recommended by the European Commission is shown.

Secondly, consumers are requested not to dispose of WEEE as unsorted municipal waste and to collect it separately. Therefore, customers play a major role on this activity by delivering products to suitable places and by their buying attitude towards green products. Consumers must pay a fee to fund the recycling of

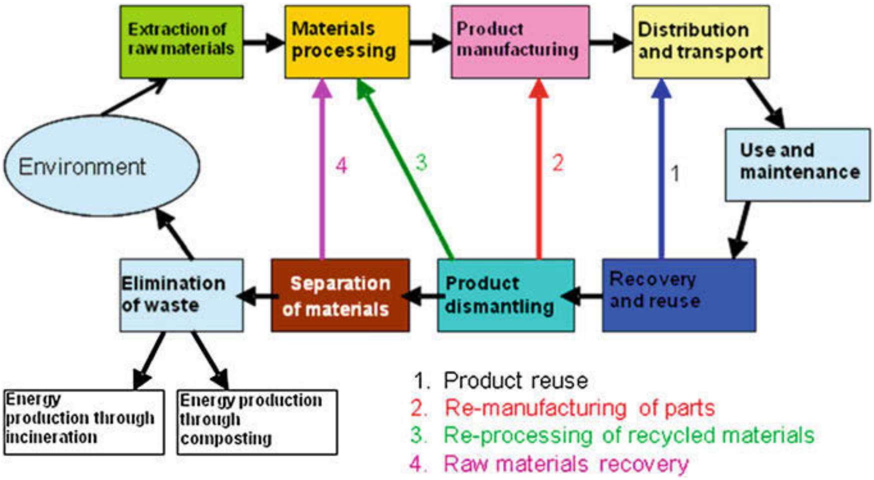


Fig. 1 Treatment recommended by the European Commission for end-of-life products

the machine and to prevent heavy metals from contaminating the environment such as chromium, barium, cadmium, mercury, flame retardants. Consumer awareness then is very important to return e-waste to separate collection points. The dichotomy between legality and morality is a good measure of what should be a green citizen.

Finally, municipal waste collection must be promoted and convenient facilities should be set up for the return of WEEE including public collection points that allow returning waste free of charge.

An objective of 4 kg/person/year of selected WEEE collection was established by 31 December 2006, and a minimum ratio of 50–80% of recycled or reused material and/or component must be achieved, depending on the type of equipment. Figure 2 shows the WEEE collection rate for the different European countries in kilograms per inhabitant in 2008 (Eurostat 2011). As shown in the figure, most countries comply with the directive. However results show that from the WEEE that are collected in Europe, just a 60% is treated in Europe and the rest is exported mainly to Asia and Africa, illegally.

E-waste treatment is beginning to become profitable. But since it is necessary to invest in treatment plants, that are often expensive, economies of scale are needed in terms of minimum volumes of products to be recycled. Moreover the environmental impact of the collection process and the recycling process should also be taken into account. In some countries it still happens that junkmen collect more e-waste than treatment plants because they pay more for the products than these companies. But specific treatment of WEEE is essential to avoid the dispersion of pollutants in order to prevent negative environmental impact.

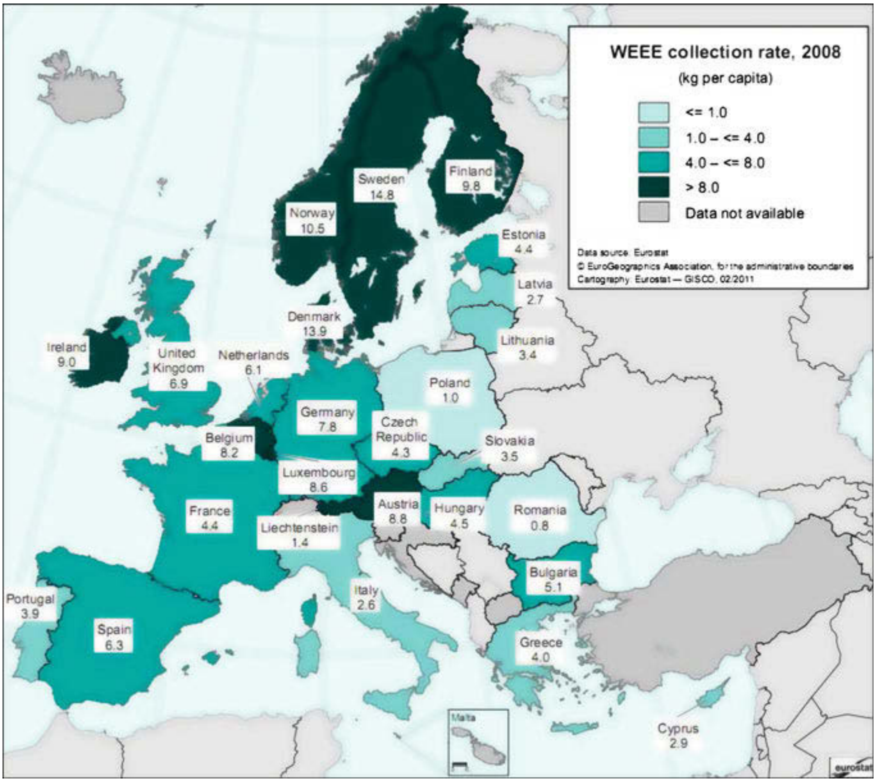


Fig. 2 WEEE collection rate in Europe. *Source* Eurostat, © EuroGeographics Association

3 State-of-the-Art

Computers, televisions and other electronic scrap contain valuable materials and components, which may be recyclable and reusable. There are also toxic and hazardous substances contained in electronic waste which must be identified and separated.

Glass represents the largest proportion of material, (25% in weight), in the flux coming from television sets and monitors, being the main component of the cathode ray tubes (CRTs). Sometimes it is necessary to separate panel and funnel parts of the CRT, since the two fractions are reused in different ways due to their content of lead and other components, which restricts its future reuse. Metal fractions constitute the second group of components (iron, aluminum, copper and other precious metals), being foundry the most common destination. Among the non ferrous metals, lead, zinc and tin are obtained. Plastics are the third group. They may include potential hazardous components, mostly halogenated plastics used as flame retardants. Other components which can be found are rubber, silicone and, sometimes, wood.

Different cost models for the recycling process have been suggested. "Technical cost modelling" (Kang and Schoenung 2006) is based on the addition of process-derived costs, performed in several steps. A general rule in the computation of the cost-effectiveness of schemes of take-back and product recovery is that it has to be done looking at the whole process chain, combining both transport and product treatment. Nagel and Meyer (1999) proposed a method to plan integrated and cost optimized take-back and recovery systems, customized for manufacturers, retailers, logistic managers or recycling companies.

In a "traditional" manufacturing process, the main objective is to complete a product on time and within costs limits. But, unlike manufacturers, in the world of recycling priorities are different. There is no due date, and the goal is not the time when the final "products" (raw materials or dismantled parts) are extracted from disposed devices. Aim for electronics recycler is to maximize revenues for the sale of recovered materials, and to maximize available space in the reception area of the plant (part of the income comes just from receiving shipments) (Sahoo et al. 2005).

Several solutions have been suggested to maximize the recycling rate, giving priorities to different types of waste: processing products that can most quickly be taken apart, taking first the largest products, or processing the most valuable products first.

One technique that has been successfully applied to recycling is simulation. Simulation models generally use a large number of parameters, depending on the difficulty of the dismantling operation and try to obtain an automatic disassembly sequence. Main goals for these simulation models are precision-oriented operations and productivity. But most studies in this research field depend on updated information systems about appliance characteristics that are often not available (Hesselbach and Westernhagen 1999). Besides, simulation tools are more oriented to product simulation than to separation and recycling processes. But in recycling there are no due dates to be fulfilled and dismantling processing time is not so important. Moreover, the arrival of products to recycle is unpredictable (Kang and Schoenung 2006).

Dismantling operations are usually performed manually. But high future demand for those appliances that will become obsolete within a short period of time requires a higher degree of automation.

Considering the previous study we can draw the following conclusions:

- At the industrial level, there are no automated lines, except for virtual prototypes.
- Planning and simulation solutions are difficult to implement, and complex to solve.
- They highly depend on updated information systems related to the equipment that are often not available (Kim et al. 2006).
- Simulation is oriented to product, not to recycling processes (Lambert 2002; Gerner et al. 2005).

Currently a proper separation of materials and components of electronic devices has not yet been achieved because of the complexity in the internal composition of these appliances (Tang and Zhou 2001). As a result, a minimum selling price of the material obtained cannot be guaranteed and therefore a benefit to justify recycling. The recycling companies in the industry should be managed effectively, targeting the client (the prospective user of the materials obtained from recycling), optimizing quality, cost and service. These needs are those that have been taken into account in this research.

4 Proposed Methodology

The main goal of this research is the optimization of the recycling process of electronic equipments, mainly TV sets and monitors, applying technical and economic criteria, taking into account legal and environmental requirements, and generating a model according to a certain dismantling strategy and degree of materials recovery that optimizes the profitability of a recycling company.

This methodology fulfils three criteria:

- **Technical:** These are mainly related to a disassembly according to the characteristics of the equipment. Besides, the availability of means of transport, handling and treatment must be ensured.
- **Economical:** The materials recovered must be accepted by some potential customers, possibly at secondary market prices and the recovery costs must be low enough to allow for a positive margin on sales.
- **Legal:** The rate of recovery shall be increased to a minimum of 75% by an average weight per appliance, and the component, material and substance reuse and recycling shall be increased to a minimum of 65% by an average weight per appliance.

In Fig. 3 the methodology proposed is represented. It applies new technologies for dismantling operations, tested with simulation methods and operated in pilot plants, where results have been extrapolated to industrial scale. Furthermore, it has taken advantage of the previous expertise of an industrial recycling company.

Firstly, we perform a preliminary analysis of the economic aspects of the recycling process and technical features of the appliances:

1. Technical data of the devices to be recycled.
2. A preliminary assessment about the technical feasibility of the dismantling operations, using simulation techniques.
3. Selling prices for recovered materials.
4. Treatment cost of the recycling process (from fully automated to fully manual), obtained from simulation analysis.
5. Restrictions imposed by the WEEE European Directive (minimum recycling rate to be obtained).

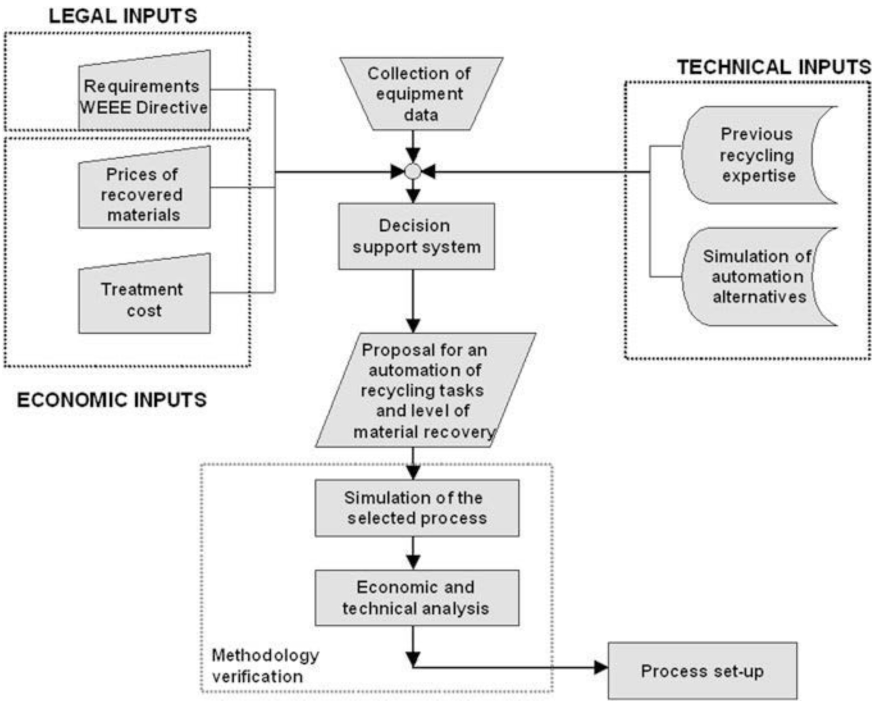
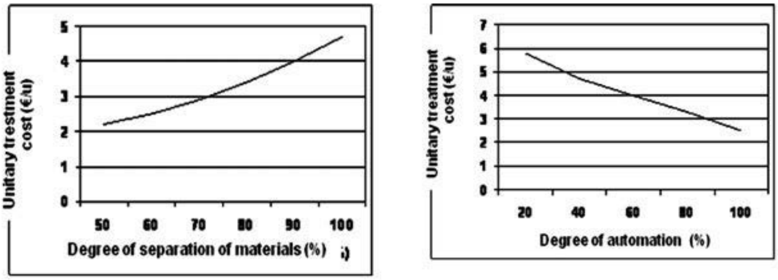


Fig. 3 Proposed methodology

We are going to focus on TV sets and monitors. Materials and components coming from dismantled appliances are usually classified into four groups: metal, plastic, Cathode Ray Tubes (CRT) and Printed Circuit Boards (PCB). Glass represents the largest proportion of material, (25% in weight) coming from television sets and monitors, being the main component of the cathode ray tubes (CRTs). Sometimes it is necessary to separate the panel and funnel parts of the CRT, since the two fractions are reused in different ways due to their relative content of lead and other components, which restricts its future reuse. Specifically, the funnel part that surrounds the electron gun has a higher lead content.

We have used an analytical simulation package that provides a detailed analysis of each operation. We have implemented three different configuration lines: fully manual fully automated and mixed. Besides, we have analyzed the relations between treatment costs and two factors: degree of separation of materials and degree of automation of the recycling process.

We have analyzed how the treatment cost is influenced by two factors: degree of separation of materials and degree of automation of the recycling process. In Fig. 4 we can see that there is a positive correlation between the degree of separation of materials and the unitary treatment cost and a negative correlation between the degree of automation and the unitary treatment cost. As it can be seen, the more precisely separated materials we want to obtain, the more expensive is



	100 % Manual >>>>>>>>>>>>>>>>>>>> 100 % Automatic						
Cost €/u	5,3	4,4	3,9	3,4	3,1	2,9	2,7
% Automation	30	40	50	60	70	80	95
% Separation	98	90	84	80	77	70	61

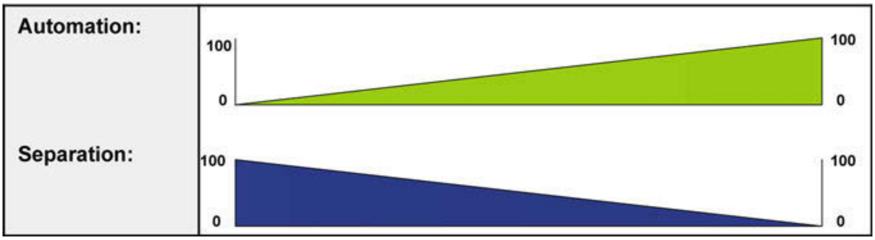


Fig. 4 Simulation results

the treatment cost since manual operations must be applied. On the contrary, using full automation leads to cheaper treatments but fewer amounts of materials correctly separated.

The data shown above have been obtained from two sources: the previous experience of the recycler and results obtained from several simulation runs. We can conclude that the higher the level of automation, the lower the treatment cost and the lower the quantities obtained from correctly separated material.

Once several treatment costs have been obtained as explained above, some legal restrictions (minimum recovery rates) and economic aspects (price of materials in the stock market) are added to the model. In order to do that, we have defined an optimization model that helps finding the best solution for achieving the highest profit margin. It makes use of a decision support system, a program that provides information in a given domain of application using analytical decision models, in order to support a person in making decisions effectively in complex and ill-structured problems.

In the recycling world, the nature of the problem is typified by an unexpected arrival of input for the process (collected electronic scrap), changing selling prices and several ways to perform the separation and recycling. The information processing method cannot be stated as an algorithm and therefore cannot be represented as a computer program.

Generally, an optimization model is composed of *an Objective Function*, *Variables* and *Constraints*. The Objective Function expresses what we want to optimize. In this case it computes the profit of the company as a function of revenues (sales of the obtained materials) and treatment costs:

$$\mathbf{PF} = \sum_{\mathrm{i}=1}^{5} (\mathbf{M_i} \times \mathbf{PR_i}) - \left(\left(\sum_{\mathrm{j}=1}^{n} \mathbf{AD_j} + \mathbf{AE} \right) \Big/ \mathbf{P} \right)$$

where

- *PF:* Unitary profit
- *i :* 5 main materials (glass, plastic, iron, steel, copper).
- *M:* Amount of material *i* obtained in the recycling process.
- *PRi*: Selling price of m
- *j :* Dismantling machines.
- *ADj:* Annual depreciation of the machines *(j = 1,..n).*
- *AE:* Annual exploitation costs.
- *P:* Annual productivity.

The variables used in this optimization model are the quantities under control in the model. Optimization looks for the values of the variables that generate the optimum value of the objective function, subject to the restrictions applied to these variables.

Finally, the constraints are the limits of the values the variables can assume (e.g. time, budget, raw materials, etc.). They are represented as functions of the model's variables. In this case the constraints are the minimum quantities of the 5 main materials to be obtained (defined by the WEEE European Directive), and some other limitations concerning technical data of the appliances:

$$AW \geq \sum_{i=1}^{5} MX_i \geq \sum_{i=1}^{5} M_i \geq \sum_{i=1}^{5} MD_i$$

where

- *AW:* Average total weight of the electronic appliance.
- *i* : 5 main materials
- *MX:* Maximum amount of material i theoretically obtainable with a 100% recycling rate.
- *M*: Amount of material i obtained in the recycling process.
- *MD*: Minimum amount of material i to be obtained in order to comply with WEEE Directive.

Table 1 Optimization results

Proposed solutions	Glass	Plastics	Iron	Aluminium	Copper
Target amount of material (Kg/unit)	7.3	3.1	1.6	0.04	0.8
In % with respect to theoretical maximum	76%	100%	100%	100%	100%

5 Application of the Model in Companies

This methodology has been applied to the recycling process of a company dealing with the disassembly of electronic scrap. The aim was to optimize the way to separate and recycle electronic appliances (TV sets and monitors) in order to obtain the maximum quantities of raw materials at the lowest cost, depending on the selling price of the materials at a given time. One challenge was the re-use of the glass coming from CRT and the valuable components coming from the printed circuit boards. Unlike iron, copper and aluminium, glass and plastics are difficult to extract, and reuse is not yet well resolved in new applications. There are experiences in the reuse of recycled crushed glass for Portland cement and concrete (Shi and Zheng 2007), although main concern is the expansion and cracking caused by glass aggregates. Seeking a new application, a manufacturer of glazed tiles was identified as a potential user of the obtained glass.

Regarding the electronic components of the printed circuit boards, the aims were to recovery and reuse the elements of high value (memories, transistors, condensers, etc.), and to extract the hazardous components (batteries, etc.).

The current parameters of the recycling company (treatment costs) and actual market prizes of the materials obtained from the TV sets were used in the model. We have executed the optimization program and simulated the operations in the recycling line. The outcome of the optimization model shows that the best option for the process is a semi-automated treatment line. In addition, the method suggests the quantity of each material to be obtained, as shown in Table 1:

The quantity of the materials determines which disassembly task should be specifically automated. Amounts of plastic, iron, aluminium and copper to be obtained should reach the maximum achievable (for this cases manual operation are recommended), while the glass should be obtained by means of semi-automated process.

Therefore, manually-operated stations in the recycling line should be used for the disassembly of TV housings (plastic), metals (iron, aluminium, copper), organic components and hazardous elements. On the other hand, a semi-automated station for the separation of the glass should be designed, with the additional requirement of the separation of the funnel and panel glass. Operation in this cell is as follows: a transportation belt is used to enter CRTs into this cell. A vision-based system identifies the presence of lead in the panel glass, which determines further treatment of the CRT, sending appropriated commands to the robot and other machines. If panel is lead free, the CRT must be separated in two parts: funnel and panel; otherwise it can be shredded without previous separation. Robot uses a

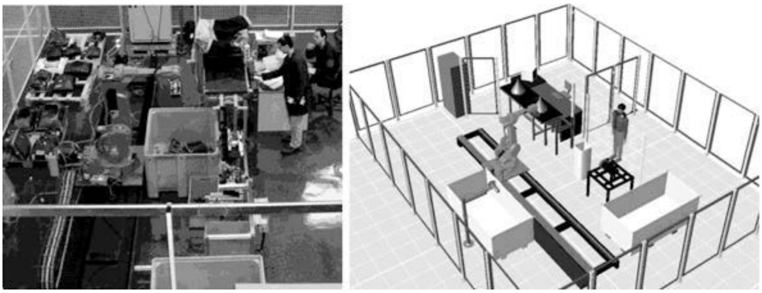


Fig. 5 General view of the recycling line (actual and simulated workshop)

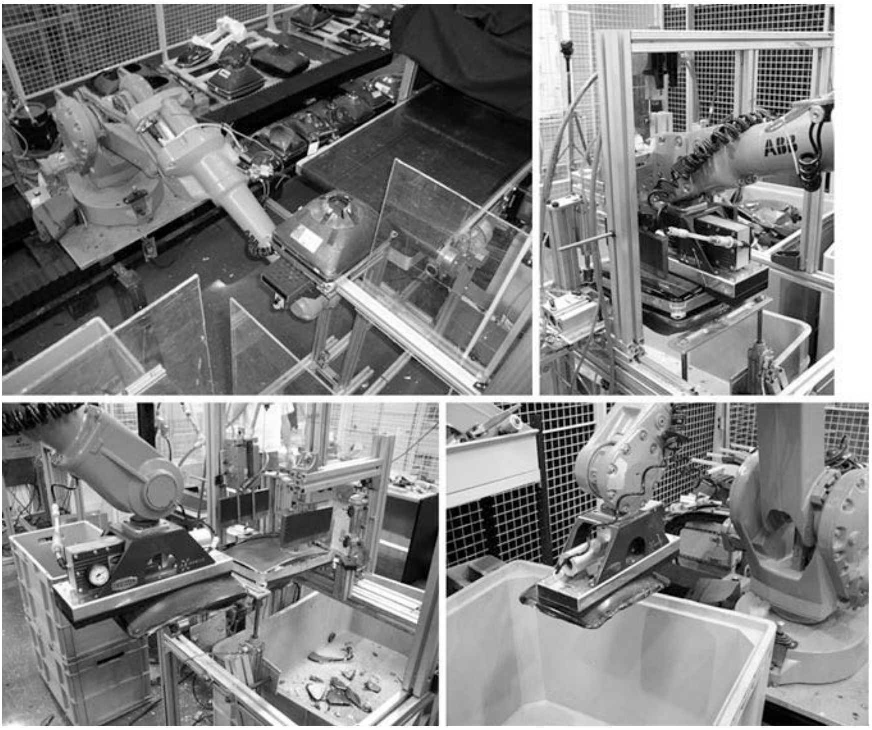


Fig. 6 Detailed views of the recycling of TV glass

vacuum gripper to handle the CRT and transport it to next workstations, where a rotating saw cuts the CRT along the joining line between panel and funnel. Funnel glass and mixed parts (metal, silicone) fall in a container. Then, robot moves to next station, only with panel part and metallic band. A similar operation is carried out, where metallic fraction falls in a container, and the robot carries the remains (panel glass) to a third container (Figs. 5, 6).

Table 2 Average amounts of materials recovered in a TV/monitor

Material	Weight of material (kg)	Sale price (euro/t)	Cost of further treatment (euro/t)
Panel glass	5.39	97.8	
Funnel glass	2.50	122.5	
Iron	1.47	320	
Aluminium	0.04	1,690.0	
Copper	0.69	4,846.6	
PVC (Polyvinyl Chloride)	0.5	101.7	
Condensers	0.005	–	1,540.0
Plastics for mechanical recycling	1.50	284.7	
Plastics for cement manufacturers	0.84	67.8	
Polypropilene	0.47	882.0	
Mixed glass, silicon	0.45	87.6	
Wood	0.20	–	−23.4

Once the recycling line was designed and built, some tests were carried out in order to compare the results with the forecast of the methodology. Table 2 shows the average amount of materials recovered from a TV/monitor in the performed implementation and their corresponding sale prices. For some specific components (toxic and hazardous materials), the figures represent the cost of further specific treatment by an officially approved manager, before their disposal in a landfill or incineration (this cost is known as "Gate Fee").

6 Analysis of Results

The results obtained by the recycling company have been assessed under two kinds of evaluations:

1. Economic studies, covering the requested investments and revenues of the developed system, following known methods as well as new and complementary analysis based on the flexible equipment used in the recycling process.
2. Technical feasibility of recovered electronic components and glass for the new proposed use.

The economic studies included the well known parameters such as *Net Present Value*, *Internal Rate of Return* and *Pay-Back Period*. They attempt to evaluate a single economic objective associated with the investment in advanced automated technology. Values obtained from these three indicators have shown that the proposed solution for the dismantling plant was profitable.

However, a deeper analysis of the justification of the investment was carried out, applying additional computing methods. The *Modified Internal Rate of Return* provided a better indication of a project's efficiency in contributing to the company's discounted cash flow. In addition, a new capital budgeting technique, called *Capital-Back* (Nilsson et al. 1992), was applied. It bears in mind the flexibility of the automation components that constitute the recycling installation. These flexible elements can be used for different purposes other than those originally intended, a very common case in the recycling of electric and electronic appliances, where the type, condition, and model of the devices vary a lot.

Formula for the calculation of the CB is:

$$CB = \frac{IInf}{OCF - (IIf - (IIf * Annuity(n, r))}$$

where

IIf: initial investment on flexible components
IInf: initial investment on non flexible components
OCF: operating cash flow in year *t*
n: life span (in years) of the project
r: project required rate of return

This index takes into account the initial investment in flexible machines (robot, handling devices, sensors, load/unload machines, computers, etc.) and the investment in inflexible components (grippers, specific fixing systems, specific dismantling tools, etc.). These additional results allow a more clear analysis of the economical feasibility of the proposed recycling line.

On the technical side, the secondary markets for the recovered materials coming from TV and monitors are:

- Funnel glass: new CRT (still manufactured in Asia).
- Mixture of funnel and panel glass: melting for metallurgy.
- Plastics coming from housings: mechanical recycling.
- Plastics with banned additives: energy recovery for concrete manufacturing industries.
- Metals: metallurgy.
- Toxic waste: authorized waste manager.
- Valuable electronic components from printed circuit boards: reuse in new or refurbished electronic equipment.

In addition, a new application for the obtained glass from the CRT has been developed, focusing on the sustainability of the whole process. A local manufacturer of glazed tiles for wall decoration foresees future problems to obtain the raw material (recycled flat glass coming from windows). Manufacturers of flat glass will use larger amounts of this same material in order to reduce the CO_2 emissions and comply with Kioto′s protocol. As a consequence, manufacturer of tiles needs an alternative source of raw material. Recycled panel glass coming from CRTs may be a solution (see Fig. 7). Some tests have been carried out and the first results are promising, although some problems have to be fixed, mainly those related to obtained colour of the tiles, impurities and risks of internal tensions. One of the influential factors may be the different level of granulation of the pounded glass (from 100 to 40 μm).

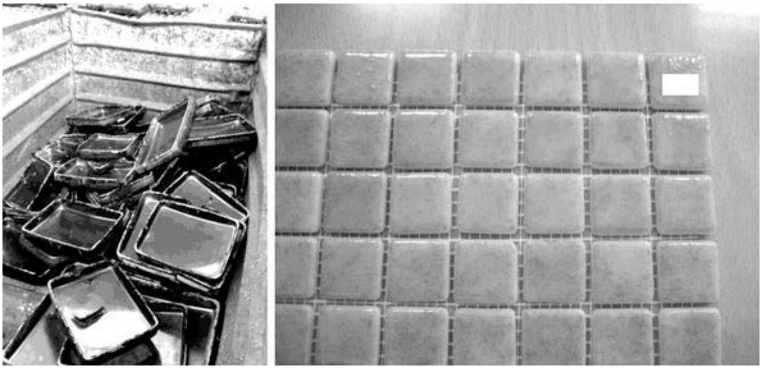


Fig. 7 Panel glass (*left*) and obtained glass tiles (*right*)

7 Conclusions

The main objective of this work is a new methodology for a selective disassembly of electric and electronic appliances, aimed at the sustainability of their re-use in similar or new applications, and with a feasible cost for the recycler. Proposed methodology has been applied to the definition of the best process configuration for dismantling of TV components, based on semi-automated operations, aimed at the best use of the obtained materials, and also to the accomplishment of the recycling targets of the European Directives. The methodology involves the use of simulation and decision support systems, which ensure the generation of an optimal set of production parameters.

The obtained dismantling process has been implemented in a practical way in a recycling company, where a final assessment on both economic and technical feasibility of proposed solution proves the suitability of the methodology. Final results asses the sustainability of the whole chain: from the collection of end-of-life electronic equipment, their classification, the optimized way to separate into components and materials in order to obtain economic benefits, and the new applications developed for the recovered materials.

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Strategic Planning and Operational Planning in Reverse Logistics: A Case Study for Italian WEEE

Riccardo Manzini and Marco Bortolini

Abstract This chapter presents a decision-support system (DSS), for the strategic planning and operational planning in reverse logistics applied to a multi-stage collection network. The DSS is based on the application of original mixed-integer linear programming models for strategic issues and heuristic algorithms for operational issues. The proposed models and solving methods have been applied to a case study of electric and electronic equipment waste WEEE collection for the city of Bologna, Italy. The results obtained by a what-if analysis have been properly presented and justified. This study demonstrates the importance and effectiveness of a hierarchical approach in order to identify the best location of facilities, the allocation of customers (e.g. origination sites) demand to suppliers (e.g. collection sites), and the vehicle routing in accordance with different transportation modes.

Keywords Strategic planning · Routing · Mixed integer programming · Environmental effects · Linear programming · Extended supply chain · WEEE

1 Introduction and Literature Review

Supply chain management (SCM) is the "design, planning, execution, control and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing

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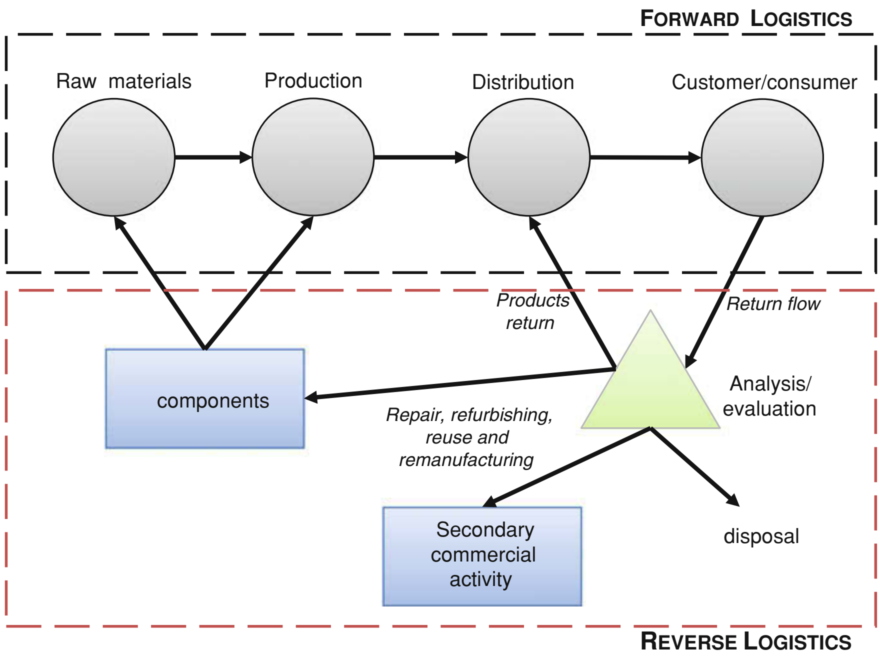


Fig. 1 Forward versus reverse logistics

supply with demand and measuring performance globally" (Manzini and Bindi 2009). In particular, during last decades SCM deals with the management of the so-called *extended supply chain* which should not only comprehend a manufacturing system where raw materials are transformed into final products and delivered to end customers/consumers, but it should also integrate the recovery system where end-of-life products are returned to recovery facilities. Consequently the supply chain (SC) includes also the process of "reprocessing". The importance of waste management and remanufacturing to achieve both environmental and economical goals has been increasingly recognized.

Reverse logistics (RL) refers to the distribution activities involved in product returns, source reduction/conservation, recycling, substitution, reuse, disposal, refurbishment, repair and remanufacturing as illustrated by the conceptual framework in Fig. 1. In particular, it clearly distinguishes the forward from the reverse logistics. RL involves the collection activity of return products at designated regional distribution/collection centers or retail outlets, the transfer and consolidation at centralized return centers, the asset recovery of returned products through repairs, refurbishment, etc., and the disposal with no commercial use (Min et al. 2006). Product returns can generate revenues through remanufacturing operations.

A classification of different configurations of reverse logistics is illustrated by Rogers and Tibben-Lembke (1999). In particular by this brief introduction and analysis of the literature it can be easily accept the following definition of reverse logistics: *The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal* (Jayaraman et al. 2003).

Literature presents a lot of studies on logistic network design, management and optimization expecially for forward logistics (Manzini and Bindi 2009; Gebennini et al. 2009; Melo et al. 2009). The number of studies is quite different for reverse logistics and significant contributions are not yet illustrated to simultaneously face the strategic and the operational planning.

The integration of RL has received significant attention by recent studies (Das and Chowdhury 2011). Recent surveys are presented by Subramoniam et al. 2009; Pokharel and Mutha (2009); Gungor and Gupta (1999); Fleischmann et al. (1997). Literature distinguishes the strategic from the operational planning issues and original contributions integrating both issues and decisions are not yet presented.

Studies on strategic planning are proposed by many contributors, e.g. Dowlatshahi (2005); Rogers and Tibben-Lembke (1999); Jayaraman et al. (2003). Some of them present models integrating forward with reverse issues (Salema et al. 2010; Fleischmann et al. 2001).

On the other hand, in operational planning, the management of routes and vehicles in RL network is discussed by some studies, e.g. Gamberini et al. (2010); Kim et al. (2009, 2011a, b); Mar-Ortiz et al. (2011). The VRP is in-depth discussed by many papers coming from the Operations Research discipline (e.g. Toth and Vigo 2002).

Effective models for the operational planning conducted with heuristic approaches based on cluster analysis—CA (cluster first) and routing (route second) are presented by Manzini and Bindi (2009).

Guide et al. (2003) discuss about the importance of quality of product returns for the determination of the acquisition prices and demand. Savaskan et al. (2004) define three different categories of reverse channels: (1) collecting directly from the customers, (2) providing suitable incentives to an existing retailer (who already has a distribution channel) to induce the collection, and (3) subcontratting the collection activity to a third party.

The aim of this chapter is the development and application of a DSS for the design and management of a reverse logistic network based on an original and hierarchical approach to the *strategic planning* and the *operational planning*. In particular, a case study for the collection of waste of electric and electronic equipment (WEEE) is presented, and the results obtained by the application of a software platform are illustrated demonstrating the effectiveness of the proposed models and approach.

2 Strategic Planning

The strategic planning deals with the configuration of the system of returns, i.e. the determination of the number of facilities, their geographical location, the process capacity and the assignment of each entity, as demand point, to the higher level, i.e. a

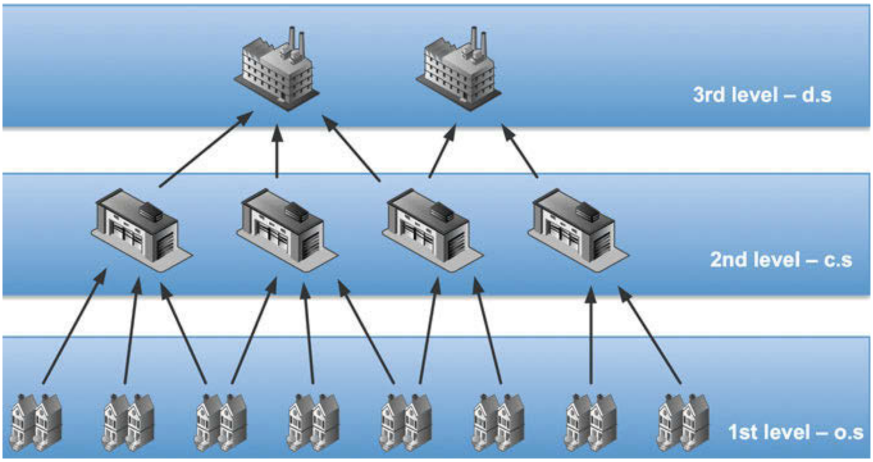


Fig. 2 Reverse logistic network, 3 levels and 2 stages (first stage o.s–c.s; second stage c.s–d.s)

supplier facility (e.g. collection site). In particular, the assignment of a demand point to a supplier implies the assignment of demand flows, which are time dependent as discussed in the next section. The return flow of components and materials is a collection process which can be modelled as in Fig. 2 in presence of three levels (*destination site* level, *collection site* level and *origination site* level) and two stages: the first stage (collection-origination) and the second stage (destination-collection). An origination site (o.s) can be a store, a retail outlet, a customer's collection station, or a customer's home. A collection site (c.s) is synonymous with intermediate transhipment site: it receives collected products from origination sites. The destination site (d.s) can be a refurbishing site/facility (r.s or r.f.), a recycling plant, a decontamination plant, the original manufacturing site.

The schematic model illustrated in Fig. 2 is that adopted by the authors of this chapter for the development of the supporting decision models and tool discussed below.

3 Operational Planning

The operational planning deals with the determination of the set of routes and trips for each supplier (e.g. a collection site at the first stage of the network) which serve a set of assigned demand points/customers (e.g. origination sites). Given a point in time *t*, e.g. a day or a week, the generic demand point has a demand of return products to be collected. As a consequence, the operational planning is time dependent and is a very complex NP-complete decision problem. This is the vehicle routing problem (VRP). For example, given a set of origination entities assigned to a specific collection site, a set of vehicle loadings and routings have to be defined in order to satisfy customers needs and system constraints, e.g. the type, availability and capacity of collection vehicles.

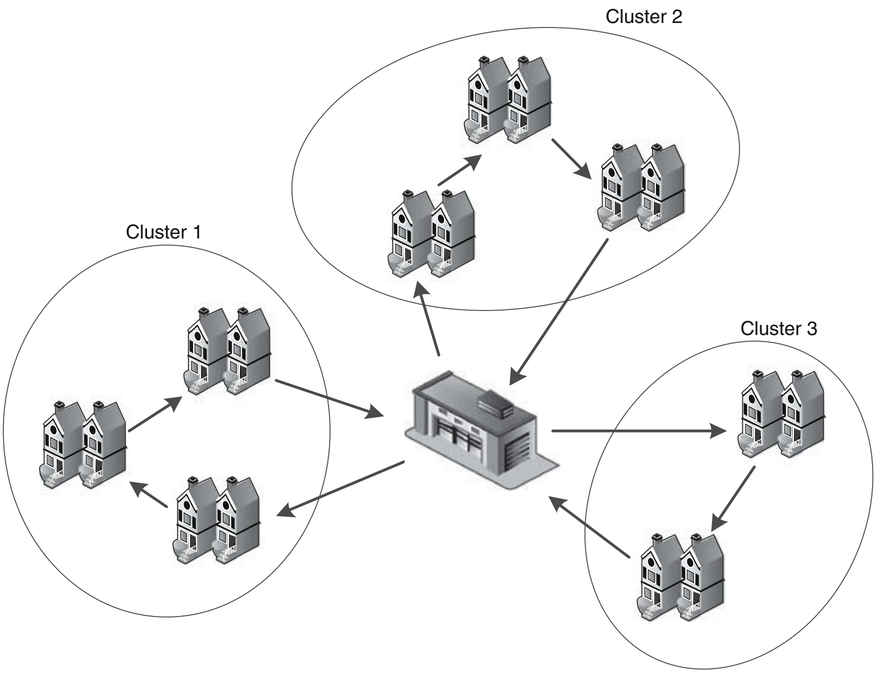


Fig. 3 Clustering and routing

Figure 3 exemplifies the so-called clustering definition problem, as a set partitioning problem, for a set of entities (origination sites—o.s in figure) assigned to a specific collection site.

4 Strategic Optimization Modelling

The proposed mixed integer linear programming (MILP) cost-based model for the strategic planning is now illustrated. It is single period, multi-product, multi-level (3 levels & 2 stages), multi-transportation mode, with (without) fractionable flows. This model can be modified in accordance with the introduction (elimination) of some constraints and/or modification of the objective function as properly illustrated in this section. In particular, it is possible to include: by-pass flows of materials from the first (origination level) to the second level (collection level) directly moving from an origination site to a destination site, or the set of constraints for non fraction ability of return flows, or the avilability of disposal facility(ies).

The aim of this model is the definition of the best configuration of the system including the assignment of entities at a lower level (e.g. origination site level), to other entities at the higher (e.g. collection site level) in order to satisfy the single period (i.e. non time dependent) demand of collection.

$$\min \phi = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P} X_{i,j,p}^{I} \cdot c_p \cdot d_{i,j} + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{p=1}^{P}\left(Y_{j,k,p}^{I} + Y_{j,k,p}^{II} + Y_{j,k,p}^{III}\right) \cdot c_p \cdot d_{j,k} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{p=1}^{P} Z_{i,k,p}^{I} \cdot c_p \cdot d_{i,k} \tag{1}$$

$$+ \sum_{i=1}^{I}\sum_{j=1}^{J} nx_{i,j}^{I} \cdot vx_{i,j}^{I} + \sum_{j=1}^{J}\sum_{k=1}^{K} ny_{j,k}^{I} \cdot vy_{j,k}^{I} + \sum_{j=1}^{J}\sum_{k=1}^{K} ny_{j,k}^{II} \cdot vy_{j,k}^{II} + \sum_{j=1}^{J}\sum_{k=1}^{K} ny_{j,k}^{III} \cdot vy_{j,k}^{III} + \sum_{i=1}^{I}\sum_{k=1}^{K} nz_{i,k}^{I} \cdot vz_{i,k}^{I} \tag{2}$$

$$+ \sum_{j=1}^{J} f_j \cdot cs_j + \sum_{k=1}^{K} g_k \cdot rf_k \tag{3}$$

$$- \sum_{i=1}^{I}\sum_{p=1}^{P}\left(S_{i,p} \cdot \left(\sum_{j=1}^{J} X_{i,j,p}^{I} + \sum_{k=1}^{K} Z_{i,k,p}^{I}\right)\right) \tag{4}$$

subject to:

$$\sum_{j=1}^{J} X_{i,j,p}^{I} + \sum_{k=1}^{K} Z_{i,k,p}^{I} = a_{i,p} \tag{5}$$

$$\sum_{i=1}^{I} X_{i,j,p}^{I} = \sum_{k=1}^{K}\left(Y_{j,k,p}^{I} + Y_{j,k,p}^{II} + Y_{j,k,p}^{III}\right) \tag{6}$$

$$\sum_{i=1}^{I} Z_{i,k,p}^{I} + \sum_{j=1}^{J}\left(Y_{j,k,p}^{I} + Y_{j,k,p}^{II} + Y_{j,k,p}^{III}\right) \le q_{k,p} \cdot m_{k,p}^{rf} \tag{7}$$

$$\sum_{p=1}^{P}\left(\frac{\sum_{i=1}^{I} X_{i,j,p}^{I}}{m_{j,p}^{cs}}\right) \le cs_j \tag{8}$$

$$\sum_{p=1}^{P}\left(\frac{\sum_{i=1}^{I} Z_{i,k,p}^{I}}{m_{k,p}^{rf}} + \frac{\sum_{j=1}^{J}\left(Y_{j,k,p}^{I} + Y_{j,k,p}^{II} + Y_{j,k,p}^{III}\right)}{m_{k,p}^{rf}}\right) \le rf_k \tag{9}$$

$$\sum_{p=1}^{P}\frac{X_{i,j,p}^{I}}{m_{p}^{I}} \le nx_{i,j}^{I} \tag{10}$$

$$\sum_{p=1}^{P} \frac{Y^{I}_{j,k,p}}{m^{I}_{p}} \leq ny^{I}_{j,k} \tag{11}$$

$$\sum_{p=1}^{P} \frac{Z^{I}_{i,k,p}}{m^{I}_{p}} \leq nz^{I}_{i,k} \tag{12}$$

$$\sum_{p=1}^{P} \frac{Y^{II}_{j,k,p}}{m^{II}_{p}} \leq ny^{II}_{j,k} \tag{13}$$

$$\sum_{p=1}^{P} \frac{Y^{III}_{j,k,p}}{m^{III}_{p}} \leq ny^{III}_{j,k} \tag{14}$$

$$cs_j, rf_k \in \{0, 1\} \tag{15}$$

$$nx^{I}_{i,j}, ny^{I}_{j,k}, ny^{II}_{j,k}, ny^{III}_{j,k}, nz^{I}_{i,k} \quad \text{integer} \geq 0$$

$$X^{I}_{i,j,p}, Y^{I}_{j,k,p}, Y^{II}_{j,k,p}, Y^{III}_{j,k,p}, Z^{I}_{i,k,p} \geq 0$$

where $i \in \{1, \ldots, L\}$ Origination site, $k \in \{1, \ldots, K\}$ Collection site, $k \in \{1, \ldots, K\}$ distribution site (facility), $p \in \{1, \ldots, P\}$ Products, f_j fixed cost for the collection site j, gk fixed cost for the refurbishing facility k, $a_{i,p}$ number of products p to be collected at site i, $m^{cs}_{j,p}$ capacity of the collection site j for product p, $m^{rf}_{k,p}$ capacity of the refurbishing facility k for product p, $q_{\ k,p}$ equal to 1 if the refurbishing facility k works on product p or 0 otherwise, m^{I}_{p} truck capacity for p, m^{II}_{p} train capacity for p, m^{III}_{p} plane capacity for p, $s_{i,p}$ saving (economic return) from product p in site i, c_p transportation cost (including processing cost and adoption of safety measure for risky products) for product p, $d_{i,j}$ distance from the origination site i to the collection site j, distance between the collection site j and the refurbishing facility k, $d_{i,k}$ distance between the origination site i and the refurbishing facility k, $vx^{\mathrm{I}}_{i,j}$ cost of a truck from the origination site i to the collection site j, $vy^{\mathrm{I}}_{j,k}$ cost of a truck from the collection site j and the refurbishing facility k, $vz^{\mathrm{I}}_{i,k}$ cost of a truck from the origination site i to the refurbishing facility k,$vy^{\mathrm{II}}_{i,k}$ cost of the train from the collection site j to a refurbishing facility k,$vy^{\mathrm{III}}_{i,k}$ cost of the plane from collection site j to a refurbishing facility k.

The variables are:

$$cs_j = \begin{cases} 1 & \text{if collection site j is active} \\ 0 & \text{otherwise} \end{cases}$$

$$rf_k = \begin{cases} 1 & \text{if refurb. facility k is active} \\ 0 & \text{otherwise} \end{cases}$$

$nx^{I}_{i,j}$ number of trucks from the origination site i to the collection site j
$ny^{I}_{j,k}$ number of trucks from the collection site j to the refurbishing facility k
$nz^{I}_{i,k}$ number of trucks from the origination site i to refurbishing facility k
$ny^{II}_{j,k}$ number of trains from the collection site j to refurbishing facility k
$ny^{III}_{j,k}$ number of planes from the collection site j to refurbishing facility k
$X^{I}_{i,j,p}$ quantity of product p from i to j by transportation mode I, e.g. truck
$Y^{I}_{j,k,p}$ quantity of product p from j to k by transportation mode I, e.g. truck
$Y^{II}_{j,k,p}$ quantity of product p from j to k by transportation mode II, e.g. train
$Y^{III}_{j,k,p}$ quantity of product p from j to k by transportation mode III, e.g. plane
$Z^{I}_{i,k,p}$ quantity of product p from i to k by transportation mode I, e.g. truck.

Now the objective function is described in detail. It is made of different contributions. The first three addenda in Eq. (1) quantify the variable transportation costs due to the type of products. Three different kinds of flows are considered: from the origination site to the collection site, from the collection site to the refurbishing facility and from the origination site to the d.s. (e.g. a refurbishing facility). For the flow from collection site to the refurbishing facility three different transportation modes generate three different contributions.

The second part of the objective function, named (2), quantifies the variable costs associated to each vehicle contribution and in agreement with the necessary number.

The third part refers to the fixed cost associated to the planning period and due to the activation of collection sites (cs_j) and refurbishing facilities (rf_k), as reported in Eq. (3). The last term quantifies the revenue due to the collection of products and it depends on the level of quality of WEEE products at the origination site (o.s).

A brief description of the model constraints is now reported.The set of constraints (5) guarantees the equilibrium of flows at the o.s: those generated and those moving from. Similarly constraints (6) refer to the equilibrium of flows at the collection sites considering the available transportation modes. (7) select the admissible entering products flows. (8) and (9) are capacity constraints respectively for the collection sites and the refurbishing facilities. Given a product type and a refurbishing facility there is a maximum level of flows assignable in agreement with the weight of the product.

The sets of constraints from (10) to (14) define and control the use of the vehicles for each type combined with the three available kinds of flows.

4.1 Variants to the Basic Model

The previously illustrated model can be modified in order to face different reverse logistic problems. A few examples:

- *Absence of by-pass flows*, i.e. direct shipments from o.s to d.s
- *Disposal facility and costs*. The basic hypothesis is that at the origination site (o.s) *i*there is a minimum percentage of flows of product p which can beprocessed by a d.s (e.g. refurbishing facility).

- *"no-collection" admissible at the origination site*. It is possible to renounce to collect products at an origination site if it is more convenient than the collection. It is also possible to quantify a new cost contribution as a penalty for each unit of product not collected.
- *Integer values for product flows*. This hypothesis significantly increases the level of complexity for the MILP model.
- *Not fractional flows*. The products at the o.s can be assignable to at least one c.s at the first stage of the system. In case the *bypass* of the collection site is admissible, the direct flow from the origination site to the d.s. (e.g. a refurbishing facility) is also non fractional.
- *Minimization of a single level of costs.*The hypothesis is to minimize not the objective function (1)–(4) but a single level contribution. At the collection site level: fixed cost, transportation costs from o.s, revenues and penalties. At the d.s level (e.g. refurbishing facility): fixed costs and transportation costs from o.s and c.s.
- *Maximization of the level of use of the resources.*

5 Operational Planning Modelling

The operational planning deals with both the first (o.s–c.s) and the second stage (c.s–d.s) of the reverse logistic network (see Fig. 1). At the first stage it plans the visiting and routing activities of the origination sites from the collection sites in agreement with the assignments defined at the strategic decisional level. Similarly at the second stage of the network the operational planning plans the short-term, e.g. daily, proposing the pool of collection sites and the sequence of visits from the operating d.s. in order to transport all products from the second to the third level (made of destination sites, e.g. refurb. facilities) of the system.

This planning adopts a systematic procedure for vehicle routing based on cluster analysis (CA) and heuristic algorithms, originally developed and applied by the authors of this chapter to face transportation problems in distribution logistic network design and planning (Manzini and Bindi 2009). This is a two phases procedure, *cluster-first* and *route-second*. Given a planning unit time t called "planning bucket" and a *supplier site*, that is a c.s at the first stage of the system or a d.s at the second one, the first phase of the proposed procedure groups the location *sites of demands*, i.e. the o.s at the first stage or the c.s at the second stage, in disjunctive clusters. Each cluster is assigned to a specific vehicle (usually a truck), which visits the elements of that cluster in order to collect all products demand in t. The sequence of visits for a cluster is the result of the second phase of the procedure in agreement with the travelling salesman problem (TSP): the minimal cost of sequencing the visits assigned to a vehicle in a time bucket t is identified by the application of optimal or heuristic algorithms. The rule is not optimal when the number of visits is large and the non-polynomial (NP) complexity of the sequencing is too high.

The 2-step procedure for the operational planning is now illustrated in detail.

5.1 Step 1, Group Formation and Cluster Analysis

The first step is based on *CA* and on the adoption of hierarchical clustering heuristic algorithms. The grouping is a problem of assignment the demand points to disjunctive clusters each of them associated to a vehicle which supplies the demand of collection (the reverse logistic flow) by the definition of a multi-stop mission of routing: one stop at each location with non null demand.

The grouping is based on the use of *similarity indices* as introduced by statistics and widely applied to several disciplines, e.g. medicine, biology, engineering and economics. In particular the generic level of similarity between two origination sites (at the first stage), i.e. two collection sites at the second stage of the system, is a measure of saving adopting the groupage strategy to visit sites and collect WEEE products.

The first task of step 1 deals with the determination of the *similarity matrix*, as the result of the adoption of a *similarity index.*

The following Eq. (16) exemplifiesa "problem oriented" similarity index, as introduced by the authors:

$$S_{A,B} = \frac{\Delta s_{A,B}}{d_{\text{no\_groupage}}(A,B)} \tag{16}$$

$$\Delta s_{A,B} = d_{\text{no\_groupage}}(A,B) - d_{\text{groupage}}(A,B) \tag{17}$$

where

$\Delta s_{A,B}$ saving distance by the adoption of the pooling strategy for the generic sites *A* and *B,* renouncing to serve them separately

$d_{\text{no\_groupage}}$(A,B) the cost of supplying *A* and *B* separately (without adopting the groupage strategy) from the supplier depot (the c.s. at the first stage of the system or the d.s at the second stage as illustrated in Fig. 1).

d_{groupage}(A,B) the cost of visiting *A* and *B* adopting the groupage strategy.

Now:

$$\begin{aligned} d_{\text{no\_groupage}}(A,B) &= x_{A,0} + x_{0,A} + x_{B,0} + x_{0,B} \\ &= 2 \cdot x_{A,0} + 2 \cdot x_{B,0} \\ x_{A,0} &= x_{0,A} \\ x_{B,0} &= x_{0,B} \end{aligned} \tag{18}$$

$$\begin{aligned} d_{textgroupage}(A,B) &= \left[\left(x_{0,A} + x_{A,B} + x_{B,0}\right) + \left(x_{0,B} + x_{B,A} + x_{A,0}\right)\right]/2 \\ &= x_{A,B} + x_{B,0} + x_{A,0} \\ x_{A,0} &= x_{0,A} \\ x_{B,0} &= x_{0,B} \\ x_{A,B} &= x_{B,A} \end{aligned} \tag{19}$$

where

$X_{i,j}$ distance between the site (e.g. a o.s or a c.s) i and the site j

0 a supplier (e.g. a collection site) which serves A and B.

By Eqs. (16)–(19):

$$\Delta s_{A,B} = d_{\text{no\_groupage}}(A,B) - d_{\text{groupage}}(A,B) = \begin{cases} \frac{x_{A,0}+x_{0,A}+x_{B,0}+x_{0,B}-x_{A,B}-x_{B,A}}{2} \\ x_{A,0}+x_{B,0}-x_{A,B} \text{ when } \begin{bmatrix} x_{A,0}=x_{0,A} \\ x_{B,0}=x_{0,B} \\ x_{A,B}=x_{B,A} \end{bmatrix} \end{cases} \quad (20)$$

The second task of the "cluster first" phase deals with the process of grouping the demand points (e.g. the o.s at the first stage of the network) in homogeneous clusters. This task is executed by the application of a capacity constraint clustering heuristic algorithm, inspired to the well known Complete Linkage (CLINK) clustering also known as Nearest Neighbour algorithm, the Single Linkage (SLINK) clustering or the Un-weighted Pair Group Using Arithmetic Averaging (UPGMA) rule. The original version of these rules does not consider capacity constraints. For this reason they have been properly modified by the authors. These algorithms can be either *hierarchical* or *partitional.* Hierarchical algorithms are generally constructive and *greedy* heuristics, which step by step generate clusters applying an *agglomerative approach*, whereas partitional algorithms decompose directly the products into a set of disjoint clusters (Aldenderfer and Blashfield 1984). A representation of the clusters arrangement generated by a clustering algorithm is a tree diagram, called *dendrogram*, with individual site at one end and a single cluster containing all sites at the other. An example of a dendrogram is illustrated in Fig. 4.

Given a dendrogram as a result of the application of a similarity index combined with a clustering rule, it is possible to choose a minimum value of similarity, knows as *threshold value of similarity (*Manzini et al. 2010*)*, to cut the dendrogram and identify groups of homogeneous sites. Given two members of a generic group, i.e. a cluster, they have a level of similarity not lower then the threshold value. The meaning and role of the similarity indices, dendrograms, similarity threshold-cut values, and clustering algorithms, is not object of this chapter. The authors deeply illustrate similar hierarchical clustering techniques and applications in others studies when applied to different decision problems: cellular manufacturing (CM) & group technology (Manzini et al. 2010), and allocation of products in a less than unit load order picking system (OPS) (Bindi et al. 2009). In both fields of research the CA revealed to be an effective tool to find good and comprehensible solutions for professionals and practitioners.

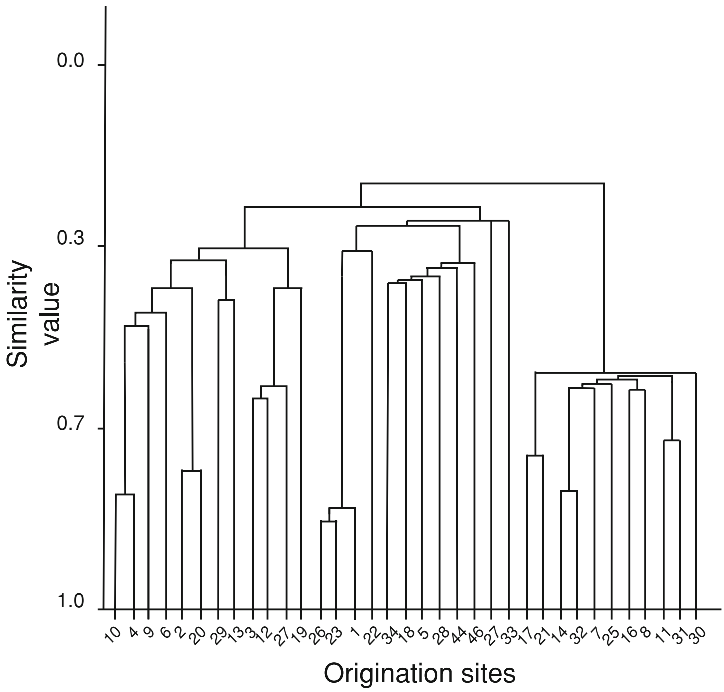


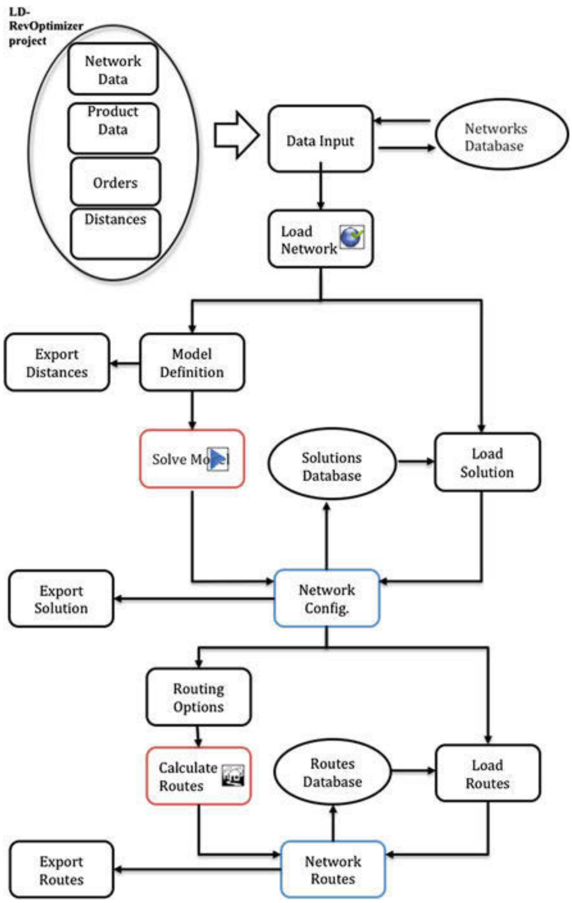
Fig. 4 Dendrogram: from o.sites to clusters, example

5.2 Step 2, Routing and Tour Definition

Given a set of clusters as a result of the previous illustrated grouping process, it is necessary to apply the TSP defined as the problem to find the shortest possible tour that visits each entity, e.g. an o.s or a c.s, in a set of entities (the cluster) exactly once. TSP is a non-polynomial (NP) problem thus difficult to solve, especially in presence of time windows. Literature presents and compares several heuristics algorithms for the TSP. We are interested in finding good feasible solutions or the best one of minimum cost when the cardinality of the set of entities is small.

The proposed and adopted operational planning procedure implements the previously illustrated 2-phases heuristics. All demand quantities are preliminary grouped in time buckets and than grouped in distinct clusters by the adoption of the similarity based heuristics. Each cluster is assigned to a vehicle defining a possible multi-stop vehicle trip (route), i.e. a travelling mission.

Fig. 5 Logic framework, LD-RevOptimizer



6 LD-RevOptimizer Decision-Support System

Figure 5 illustrates the logic framework of the proposed and original supporting decision platform, named LD-RevOptimizer, for strategic and operational planning in RL. The strategic planning is supported by the automatic creation/definition of a MILP model (see "Model definition" activity in Fig. 5) whose basic configurations have been reported in previous section. It deals with single period demand at the o.s (e.g. annual demand of recovery). The optimization model is solved by the application of a solver, e.g. IBM ILOG CPLEX, and the obtained logistic system configuration is the basis for the application of vehicle routing by clustering and heuristic procedures (operational planning). Input data, generated models and output (system/network configuration and KPIs, the so-called "Network solution" in Fig. 5) are stored in a dedicated database. This platform can be used to execute multi-scenario what-if analysis in order to best define the configuration of the system, the entities/sites assignment (e.g. the assignment of o.s to c.s and c.s to d.s), and the vehicle routing in the short term, e.g. daily, operational planning. The platform has been developed in Visual C#, also including the original procedures, rules and adopted heuristics. The computational complexity of the decision problems is non-polynomial (NP), but the solving time of the proposed models is about few minutes also in presence of hundreds of origination sites and a few collection sites, e.g. 7–10 locations, as it happens in regional collections and distribution of WEEE. The following case study exemplifies the obtained results by the application of the proposed models and tools to the Italian city of Bologna.

7 Case Study

A case study of a reverse logistic network design and vehicle routing for WEEE products is now presented. This is the problem of collection WEEE in the north of Italy and in particular in the city of Bologna. The number of origination sites is 350: they correspond to the users of electronic products, i.e. citizens of Bologna, generating a collection demand during a period of 1 month and assuming the hypothesis that WEEE products collection starts at the first level of the system by the users/citizens' demand. The number of available collection sites is 27. The system is made of 7 d.s. (refurbishing facilities) and 5 kinds of products named as R1,…,R5, e.g. R3 are TVs, displays and LCDs. Historical demand values of returns for a planning period of 1 month are the input for the proposed platform: this is a *realistic instance*. It is not a *real instance* because the adopted demand and location of the origination sites are stochastic, but in agreement with historical and global volumes of collected products (about 150 tons of WEEE corresponding to about 11500 pieces, i.e. units of WEEE). In particular, today in the city of Bologna the origination sites, as generators of collection demand, correspond to the so-called "distributors" of electronic products, e.g. shops: the adopted hypothesis of considering citizens gives the authors of this chapter the opportunity to test and validate the proposed models and tools with a more complex instance, that includes a larger number of actors at the first stage of the network. For this reason the proposed case study needs to be considered realistic.

The following tables report the input data, which refer to each level of the system. Table 1 lists the location of the origination sites (as a partial list), while Table 2 reports location, capacity and fixed costs for each cs considering a period of 1 month. Similarly, Table 3 refers to the input data for the set of d.s. The number of demand orders at the origination sites is 2856 for the considered planning period. Each order is made of different quantities of products at different level of quality: Table 4 exemplifies a few orders. Finally Table 5 reports the basic input data that refer to the different kinds of categories of WEEE products. The location of the generic o.s has been generated in agreement with the population density in each area of Bologna.

Figure 6 presents the data load form in LD-RevOptimizer for the case study object of this section when input data has been properly uploaded. In particular, o.s (red dots), c.s. (green triangles) and ref. facilities (blue rectangles) are visible on the map.

Table 1 Origination sites (o.s) locations

Name	Address	City	Province	ZIP	Country
OS1	Largo Bartolo Nigrisoli	Bologna	BO	40133	Italy
OS2	Via Attilio Muggia	Bologna	BO	40126	Italy
OS3	Via Michelino	Bologna	BO	40128	Italy
OS4	Via Franco Bolognese 29	Bologna	BO	40129	Italy
OS5	Via San Rocco 4	Bologna	BO	40122	Italy
OS6	Via Tintoretto 7	Bologna	BO	40133	Italy
OS7	Via Leopoldo Fregoli	Bologna	BO	40127	Italy
OS8	Via Cristoforo Colombo	Bologna	BO	40131	Italy
OS9	Via Faustino Malaguti 15	Bologna	BO	40126	Italy
OS10	Via Alfredo Calzoni 8	Bologna	BO	40128	Italy
OS11	Via Mascarella 65	Bologna	BO	40126	Italy
OS12	Via Vincenzo Casciarolo	Bologna	BO	40127	Italy
OS13	Via Giuseppe Ruggi 10	Bologna	BO	40137	Italy
OS14	Via Adelaide Ristori 14	Bologna	BO	40127	Italy
OS15	Via della Selva Pescarola 25	Bologna	BO	40131	Italy
OS16	Via Sebastiano Serlio 4	Bologna	BO	40128	Italy
OS17	Via Gustavo Modena 21	Bologna	BO	40127	Italy
OS18	V le Angelo Masini	Bologna	BO	40126	Italy
OS19	Via San Carlo 5	Bologna	BO	40121	Italy
OS20	Piazza della Resistenza 5	Bologna	BO	40122	Italy
OS335	Via Fondazza	San Benedetto Val di Sambro	BO	40048	Italy
OS336	Via Magione	Bazzano	BO	40053	Italy
OS337	Via a Gordini	Bazzano	BO	40053	Italy
OS338	Via Monte Grappa	Vergato	BO	40038	Italy
OS339	Via a Masi	Anzola dell'Emilia	BO	40011	Italy
OS340	Via Olmo	Anzola dell'Emilia	BO	40011	Italy
OS341	Via Claudio Monteverdi	Argelato	BO	40050	Italy
OS342	Via Enrico Mattei 49	Bologna	BO	40138	Italy
OS343	Via 2 Agosto 1980	Castenaso	BO	40055	Italy
OS344	Via V Golinelli	Castenaso	BO	40055	Italy
OS345	Via Comunale Cento	Pieve di Cento	BO	40066	Italy
OS346	Corso Giuseppe Garibaldi	Ozzano dell'Emilia	BO	40064	Italy
OS347	Via Miana	Marzabotto	BO	40043	Italy
OS348	V le Guglielmo Marconi	Loiano	BO	40050	Italy
OS349	Via Massumatico	San Pietro in Casale	BO	40018	Italy
OS350	V le Palmiro Togliatti	Crespellano	BO	40056	Italy

7.1 Strategic Planning Results

Figure 7 presents the proposed original tool developed by the authors after the execution of the strategic planning. Optimized flows of materials (i.e. allocation of demand quantities to suppliers) at the first and at the second stage of the network are visible.

Table 2 Collection sites (c.s) location, capacity and fixed cost (ref. planning period 1 month)

Name	Address	City	Province	ZIP	Country	Capacity	Fixed costs
Bologna Budrio Olmo	Via Olmo 33	Budrio	BO	40054	Italy	20760	1038
Bologna Castel San Pietro Meucci	Via Meucci	Castel San Pietro Terme	BO	40024	Italy	9760	488
Bologna Castello Di Serravalle	Via Dell'Agricoltura 52	Castello Di Serravalle	BO	40050	Italy	4260	213
Bologna Castenaso Marano	Via Marano 1	Castenaso	BO	40055	Italy	11260	563
Bologna Galliera Veneto	Via Vittorio Veneto 4	Galliera	BO	40015	Italy	6500	325
Bologna Granarolo Dell'Emilia Marsiglia	Via Marsiglia	Granarolo Dell'Emilia	BO	40057	Italy	4000	200
Bologna Malalbergo Castellina	Via Castellina 31/B	Malalbergo	BO	40051	Italy	3500	175
Bologna Minerbio Lavoro	Via Del Lavoro 8	Minerbio	BO	40061	Italy	4760	238
Bologna Monte San Pietro Bacchello	Via Bacchello 1	Monte San Pietro	BO	40050	Italy	4260	213
Bologna Monterenzio Pradella	Via Pradella 1	Monterenzio	BO	40050	Italy	3760	188
Bologna Monteveglio Abitazione	Via Abitazione 2	Monteveglio	BO	40050	Italy	21260	1063
Bologna Mordano Zaniolo	Via Zaniolo	Mordano	BO	40027	Italy	1760	88
Bologna Ozzano Emilia Sport	V le dello Sport	Ozzano Dell'Emilia	BO	40064	Italy	12500	625
Bologna San Giorgio Di Piano Stalingrado	Via Stalingrado 16	San Giorgio Di Piano	BO	40016	Italy	16900	845
Bologna San Pietro In Casale Asia	Via Asia 497	San Pietro In Casale	BO	40018	Italy	10300	515
Bologna Sasso Marconi Vizzano	Via Vizzano 11/2	Sasso Marconi	BO	40037	Italy	27200	1360
Bologna Stradelli Guelfi	Via degli Stradelli Guelfi	Bologna	BO	40138	Italy	153100	7655
Bologna Tolmino	Via Tolmino 54	Bologna	BO	40134	Italy	11000	550
Imola Faenza Casalfiumanese Casalino	Via Casalino 1	Casalfiumanese	BO	40020	Italy	1760	88
Imola Faenza Castel Bolognese Canale	Via Canale 496	Castel Bolognese	RA	48014	Italy	5500	275
Imola Faenza Castel Guelfo Casola	Via Casola	Castel Guelfo Di Bologna	BO	40023	Italy	3760	188
Imola Faenza Dozza Volta	Via Volta Toscanella	Dozza	BO	40050	Italy	5760	288
Imola Faenza Lasie Laguna	Via Lasie	Imola	BO	40026	Italy	35000	1750
Imola Faenza Medicina S.Rocco	Via S.Rocco 1	Medicina	BO	40059	Italy	13500	675
Imola Faenza Righi	Via Righi	Faenza	RA	48018	Italy	11760	588
Imola Faenza Solarolo Roma	Via Roma	Solarolo	RA	48027	Italy	2500	125
Imola Faenza Zola Predosa Roma	Via Roma 65	Zola Predosa	BO	40069	Italy	55000	2750

Table 3 Destination sites (d.s) location, capacity and fixed cost (ref. planning period 1 month)

Name	Address	City	Province	ZIP	Country	Capacity	Fixed Costs
ITALMETALLI srl	Via Confortino 29	Crespellano	BO	40056	Italy	100000	5000
Tred Carpi	Via Remesina esterna 27	Fossoli di Carpi	MO	41012	Italy	1000000	50000
DISMECO Bologna	Via Vittorio Peglion 2	Bologna	BO	40128	Italy	160000	8000
DISMECO Marzabotto	Via Lama di Reno 32	Marzabotto	BO	40043	Italy	800000	40000
RE.MA.IND srl	Via Selice 9	Mordano	BO	40027	Italy	50000	2500
Carbognani Metalli Spa	Via Emilio Lepido 180	Parma	PR	43027	Italy	700000	35000
Ferraresi commercio rottami	Via Seminiato 96	Copparo	FE	44034	Italy	1250000	62500

Table 6 summarizes main obtained results by the strategic panning. The direct distance hypothesis is adopted to measure the transportation cost from a generic o.s to the assigned c.s. at the first level of the network, and from the generic c.s to the d.s at the second stage. The largest amount contribution in terms of travelled distance is due to the first stage (about 63000 km). This is due to the large number of o.s involved during the planning period and the large number of demand orders. Uncollected returns are admissible in agreement with the Eq. (18). The existence of fixed costs for the generic facility justifies the choice to reduce the number of opened refurbishment facilities to 1 even if 7 (Table 3) are available and the number of CS to 3 even if 27 are available (Table 2).

7.2 *Operational Planning Results*

Figure 8 presents the form of the proposed tool illustrating the results obtained by the operational planning. The list of routes is presented and for each route it is possible to show the detailed instructions necessary to plan the tour as exemplified in Fig. 9: the illustrated route is made of 7 stops/visits corresponding to an equal number of origination sites.

Table 7 reports main obtained results from the operational planning adopting the following hypotheses and model settings: time bucket equal to 3 days, i.e. the demand of products for three consecutive calendar days at the generic demand point (e.g. o.s at the first stage, c.s at the second) are grouped together; Pearson similarity index (this is a not an oriented similarity index); SLINK clustering algorithm; level of similarity threshold value corresponding to the 75° percentile of aggregations as generated by the clustering algorithm and represented by the dendrogram. The number of clusters formed at the first stage is 403, differently

Table 4 A few orders of WEEE demand (ref. march 2011)

Date	OS	Product	Quantity	Quality
01/03/2011	OS56	R1	1	0.98
01/03/2011	OS83	R1	1	0.98
01/03/2011	OS264	R1	2	0.98
01/03/2011	OS278	R1	1	0.98
01/03/2011	OS311	R1	1	0.95
01/03/2011	OS333	R1	1	0.95
01/03/2011	OS6	R2	2	0.84
01/03/2011	OS45	R2	1	0.84
01/03/2011	OS48	R2	4	0.84
01/03/2011	OS60	R2	3	0.91
01/03/2011	OS63	R2	3	0.91
01/03/2011	OS64	R2	3	0.91
01/03/2011	OS75	R2	3	0.91
01/03/2011	OS77	R2	3	0.88
01/03/2011	OS81	R2	3	0.88
01/03/2011	OS134	R2	2	0.88
01/03/2011	OS146	R2	3	0.88
01/03/2011	OS160	R2	4	0.95
01/03/2011	OS188	R2	2	0.95
01/03/2011	OS217	R2	5	0.95
01/03/2011	OS222	R2	3	0.92
01/03/2011	OS261	R2	4	0.83
01/03/2011	OS270	R2	1	0.9
01/03/2011	OS293	R2	2	0.9
01/03/2011	OS310	R2	2	0.87
01/03/2011	OS322	R2	3	0.94
01/03/2011	OS330	R2	2	0.94
01/03/2011	OS332	R2	4	0.94
01/03/2011	OS340	R2	2	0.94
01/03/2011	OS346	R2	4	0.82
01/03/2011	OS14	R3	3	0.88
01/03/2011	OS32	R3	2	0.95
01/03/2011	OS67	R3	5	0.95

Table 5 Adopted hypotheses for WEEE products

Product	Mass (Kg)	Volume (m^3)	Cost/km	Savings (€/pc)	Penality (€/pc)	Disposal Cost (€/pc)
R1	50	0.8	0.003	3	10.25	10
R2	20	0.4	0.002	1.2	4.6	4
R3	10	0.2	0.002	0.6	2.05	2
R4	5	0.3	0.002	0.3	0.95	1

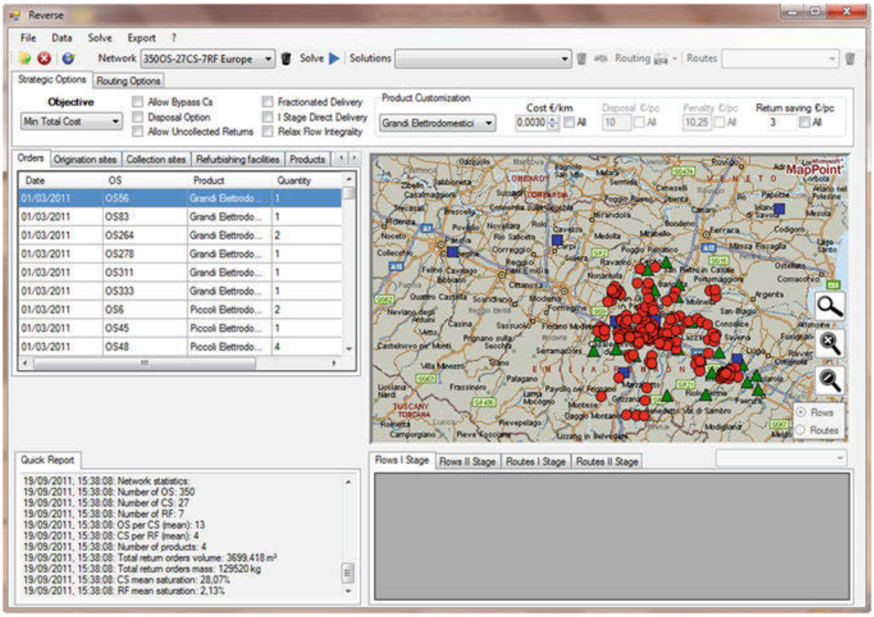


Fig. 6 LD-RevOptimizer, data load

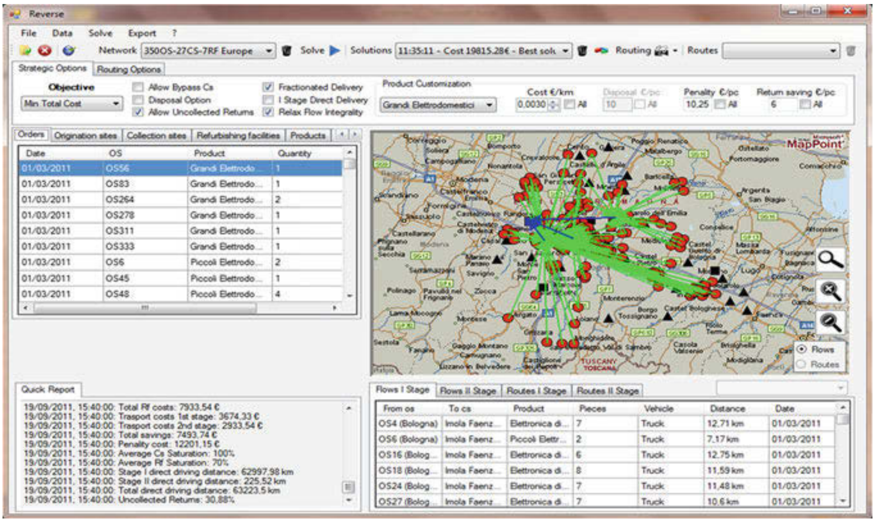


Fig. 7 LD-RevOptimizer, strategic planning

Table 6 Strategic planning results

Number of OS	350
Number of CS	27
Number of RF	7
OS per CS (mean)	13
CS per RF (mean)	4
Number of products	4
Total return orders volume [m^3]	3699.418
Total return orders mass [kg]	129520
CS mean saturation	28.07%
RF mean saturation	2,13%
Collection Sites to open	3
Refurbishing Facilities to open	1
Total Cost [€]	19815.28
Total fixed operating costs [€]	8500
Total Cs costs [€]	11881.74
Total Rf costs [€]	7933.54
Transport costs 1st stage [€]	3674.33
Transport costs 2nd stage [€]	2933.54
Total savings [€]	7493.74
Penality cost [€]	12201.15
Average CS Satu ration	100%
Average Rf Saturation	70%
Stage I direct driving distance [km]	62997.98
Stage II direct driving distance [km]	225.52
Total direct driving distance [km]	63223.5
Uncollected Returns	30.88%

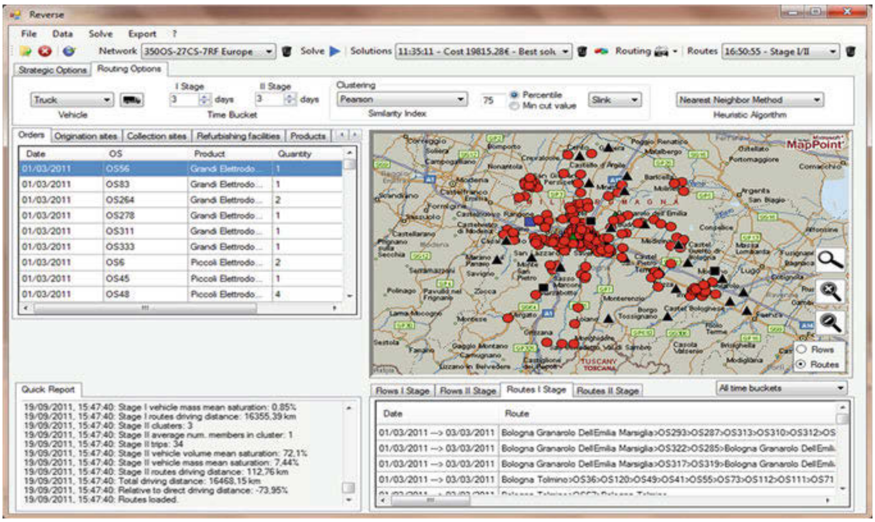


Fig. 8 LD-RevOptimizer, operational planning

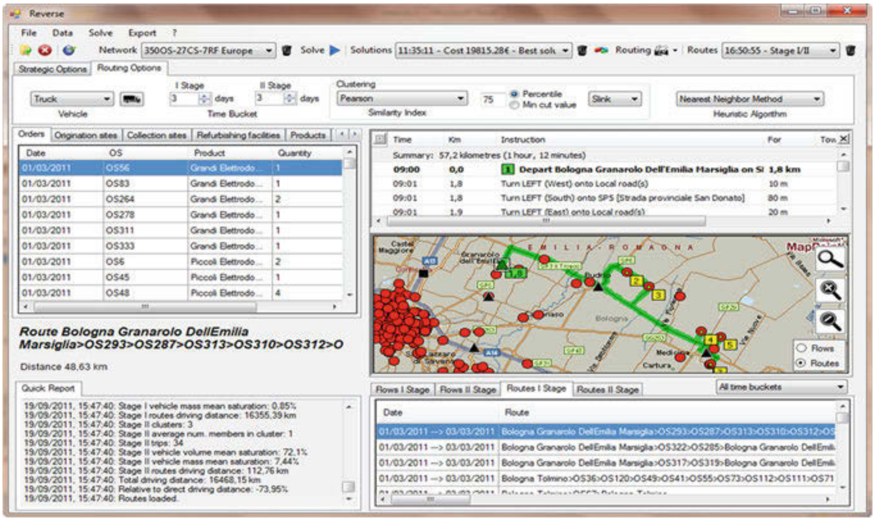


Fig. 9 LD-RevOptimizer, exemplifying route (7 o.s involved)

Table 7 Operational planning results

Stage I clusters: 403
Stage I average num. members in cluster: 3.64
Stage I trips: 404
Stage I vehicle volume mean saturation: 8%
Stage I vehicle mass mean saturation: 0.85%
Stage I routes driving distance [km]: 16355.39
Stage II clusters: 3
Stage II average num. members in cluster: 1
Stage II trips: 34
Stage II vehicle volume mean saturation: 72.1%
Stage II vehicle mass mean saturation: 7.44%
Stage II routes driving distance [km]: 112.76
Total driving distance [km]: 16468.15

populated: the average number of members for each cluster is about 4 o.s. The necessary number of trips to collect products demand adopting the groupage hypothesis is 404. The vehicle saturation level is very low and the corresponding travelled distance is 16355 km. The level of saturation in terms of volume for the generic tuck considering the second stage is about 72% corresponding to about 112 travelled km. The whole travelled distance quantified by the operational planning in order to satisfy the demand of collection at both the o.s (first stage) and the c.s (second stage) is about 26% of the direct distance in case of not adoption of the groupage strategy (as demonstrated by comparing Table 6 and Table 7).

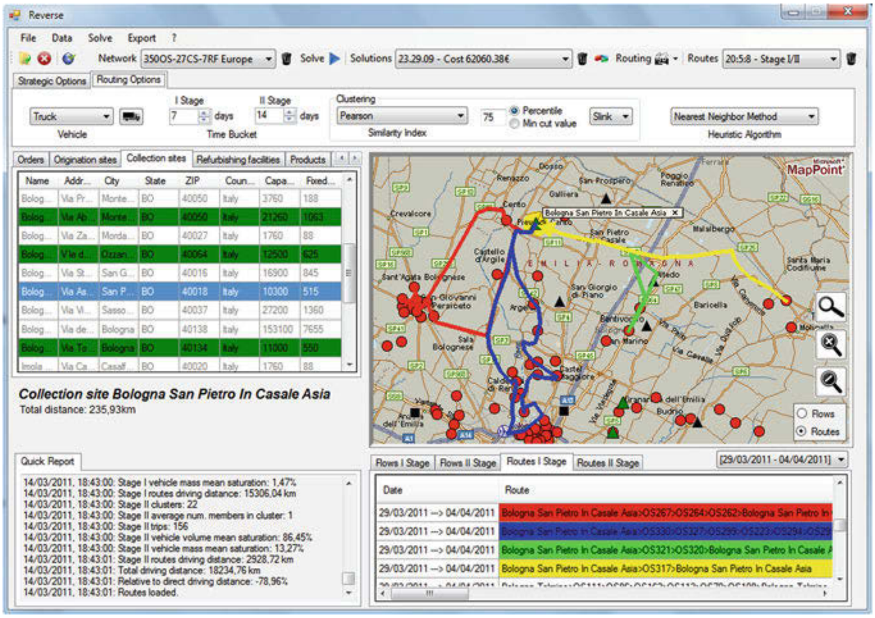


Fig. 10 LD-RevOptimizer, VRP example

Figure 10 presents different routes, corresponding to different colours, departing from a specific collection site during a period of time, i.e. a tempoal batch called *planning bucket*: the planning period is 1 month but collection return flows generated at the origination sites are grouped in bucket periods of duration 3 days. This is the well-known vehicle routing problem (VRP). The adopted vehicle is the truck.

8 Conclusions and Further Research

This chapter presents an original framework for the strategic and operational planning issues in reverse logistics by the development of original models and solving methods. A software platform has been also developed and applied to a significan case study of collection WEEE products in the city of Bologna, Italy. This application demonstrates the potential benefits of a DSS for the minimization of costs and the reduction of the environmental effects due to reverse logistics and in particular to transportation and vehicle routing. Industry is used to adopt decision-support systems (DSS) for planning and control activities, but mainly for the so-called "direct flow" of products and materials: new and special needs and opportunities are generated by the "return/reverse flow".

Further research are expected on the full integration of strategic and time dependent operational issues. In particular new case studies and application, including experimental what-if analyses, are expected. Also the evaluation of environmental effects is a topic of interest.

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Efficient Vehicle Routing Practices for WEEE Collection

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Abstract This chapter explicitly shows how the European Union Directive 2002/96/EC on Waste of Electrical and Electronic Equipments (WEEE) might be transformed into efficient vehicle routing practices for the collection of end-of-life electronic appliances. The chapter presents integer programming formulations and extensions for the problem. Due to the computational complexity of the problem, it is important to develop polinomial time heuristics solution procedures. The chapter analyzes the performance of two algorithms: a savings based algorithm and a GRASP based algorithm. Computational results indicate that the performance of the proposed algorithms to handle a real-life problem in the northwestern Spain is satisfactory. The chapter concludes with a general discussion of vehicle routing practices for the efficient collection of WEEE.

Keywords Reverse logistics · Vehicle routing problem · Metaheuristics · WEEE

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1 Introduction

The strong increase in solid waste generation has gone from being a threat to be a real worldwide problem. In recent times, over 90% of the electronic waste still ends up in landfills, causing serious environmental problems. As a result, the study of environmental problems involved in the management of Waste of Electric and Electronic Equipments (WEEE) has been a matter of interest in the recent years. Some studies have focused on developing cost-effective and environmentally friendly recycling systems (Cui and Forssberg 2003; Rahimifard et al. 2009), while other have been oriented to obtain more knowledge about the environmental consequences of the different treatment options (Hischier et al. 2005). The recycling of WEEE is an important subject not only from the point of view of waste treatment but also from the recovery of valuable materials. However, it should be noted that a recovery system (including the recycling system) is as good as its recovery network. Our study about the vehicle routing issues on WEEE logistics is motivated by this fact. According to (Hischier et al. 2005), the collection of WEEE seems much more relevant than the sorting and dismantling activities. In a recent study on the environmental impact of European regulations on WEEE recycling (Barba-Gutierrez et al. 2008) shows that inefficient recovery networks could cause even greater environmental impacts in transport collection than those avoided by recycling practices.

From a logistical point of view, the design of a recovery network has two main components: the location of collection depots and for each one of them, the design of the collection routes between its associated stores. Both problems fall into the reverse logistics management field. The first one aims to select which depots must be opened within a list of candidate sites, and to allocate collection points (stores) to depots. The second relates to the design of collection routes with capacitated vehicles. Reverse logistics literature contains examples and case studies on each one individually, for example (Shih 2001; Hu et al. 2002; Aras et al. 2008; Walther et al. 2008; Grunow and Gobbi 2009; Mar-Ortiz et al. 2011a) studied the location of collection depots, while (Schultmann et al. 2006; Blanc et al. 2006; Kim et al. 2009; Mar-Ortiz et al. 2011b) analyzed the collection routing problem. The design of recovery networks may be approached by facility location models or by territory design models (Fernández et al. 2010), but the design of collection routes may only be approached by vehicle routing models.

In this chapter we focus on the collection process. It specifically addresses the problem of designing efficient vehicle routing practices for WEEE collection. To do it, the remainder of this section analyzes and discusses the European Union Directive on WEEE from a logistical point of view. While in the following sections we describe a general framework for the WEEE collection problem, we propose mathematical programming models and compare two heuristic algorithms on real-world instances from the northwestern Spain. The chapter concludes with a general discussion of vehicle routing practices for the efficient collection of WEEE.

Table 1 The 10 WEEE product categories

1	Large household appliances
2	Small household appliances
3	IT and telecommunications equipment
4	Consumer equipment
5	Lighting equipment
6	Electrical and electronic tools
7	Toys, leisure and sport equipment
8	Medical devices
9	Monitoring and control instruments
10	Automatic dispensers

1.1 Environmental Regulations and the WEEE Directive

In view of the environmental problems caused by WEEE, many countries have drafted environmental legislation to improve the collection, reuse, recycling and other forms of recovery of such waste in order to reduce disposal.

In Europe the European Union Directive 2002/96/EC (European Parliament the Council and the Commission 2003) on WEEE was approved by the European Parliament on 27 January 2003. The WEEE directive has imposed to all member states the development of legislations based on the principle of Extended Producer Responsibility (EPR) to finance the treatment, recovery and recycling of all types of electronic waste. EPR makes the Original Equipment Manufacturer (OEM) responsible for the take-back and recovery of returned products. Its main objective is to promote reuse and recycling by imposing collection and recovery quota and to reduce electronic waste by enhancing the ecological design of products. Also, certain product recycling information must be made public and product marking must be applied to products new on the market.

The WEEE directive distinguishes 10 product categories (see Table 1) both concerning B2B and B2C markets. Within each of the categories, the producers/importers must collect the share of the WEEE which is proportional to their market share. Three recovery options are allowed: component reuse, material recycling and incineration (or energy recovery). There are two types of quota defined: the consumer electronics market has to meet a number of targets that define minimum rates, such as minimum rate of recovery of 70–80%, which includes incineration with energy recovery, and a minimum rate of component, material and substance reuse and recycling (represented by so-called weight balances) of 50–70%. It should be noted that some components from WEEE contain substances considered hazardous according to European Waste Catalog; for instance mercury in some switches, lead in solder, cadmium in batteries, glass from cathode ray tubes and other activated glass. Therefore, the treatment of the collected products is required to remove fractions or groups that contain such hazardous materials, printed circuit boards, and external electric cables. The mandatory isolation of (mostly) hazardous contents fixes a minimum degree of disassembly for products containing these

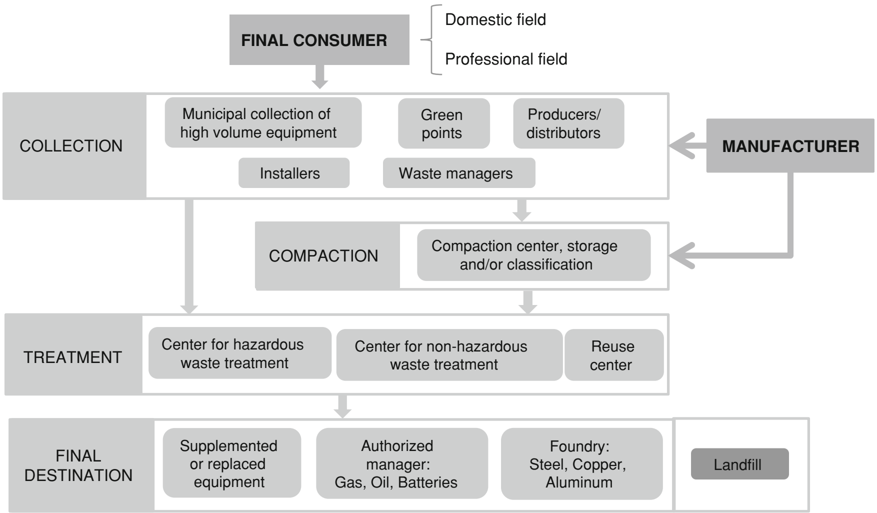

Fig. 1 The WEEE management process

substances and also the recovery route is prescribed in detail; see Annex II of the WEEE Directive.

The purpose of the WEEE directive is to prevent the creation of electrical and electronic waste and to promote reuse, recycling and the other forms of recovery in order to reduce final disposal, and to improve the environmental performance of all operations involved in the life cycle of electric and electronic equipment. These objectives will be achieved by means of: (a) extended producer responsibility, (b) design of appropriate WEEE collection systems, (c) treatment of WEEE: member states may set up minimum quality standards for the treatment of collected WEEE, and d) information: to achieve better collection rates and to facilitate recovery of WEEE.

There are several stakeholders involved in the collection and management of WEEE (see Fig. 1); however, the direct responsibility falls upon the currently acting producers and importers of electric equipment who can fulfill their obligations individually or by joining a collective scheme (see Sect. 2 on this chapter).

From a logistical point of view, the WEEE is generated when the appliances (i.e. the electrical and electronic equipment) are replaced by new ones or when they have reached the end of their useful life, even if they are not replaced. Its origin can be from the domestic (household products) or professional field. There is also a small fraction of WEEE originating from the manufacturers (producers), usually for being defective. The first stage of the management process is the collection. This can be accomplished in different ways such as municipal waste collection services for bulky equipment; in this case the city council of each municipality is responsible for the collection of WEEE and its transportation to treatment centers or intermediate facilities where there is storage pending to be recycled. Other options are the collection points, electric appliance distributors, installers and waste managers. In the second stage of the management process the treatment facilities are found. For the treatment of WEEE the authorized centers may be of several types depending on the characteristics of the waste to be treated. Sometimes, after collection, the WEEE goes through compaction process before arriving to the treatment centers. Within the process of treatment of WEEE it should be noted the role of scavenging as a special type of agents that also take part of this management system. The last stage of the process determines the final destination of the various fractions resulting from the treatment of WEEE. The role of the member states is to assure that the treatment is undertaken by competent, officially approved operators.

2 The WEEE Collection Problem

The adoption of the WEEE Directive has led to essential changes in the field of electronic scrap recycling. Particularly, producers and importers of large and small electrical appliances are affected by the new normative, since they will have to manage over 75% of the total electronic waste. To cope with this new responsibility, companies have come together to create a number of Collective Management Systems (CMS) to be responsible for the operation of collecting and recycling systems. Typically a CMS is a fund management committee created by industry associations representing the sector of manufacturers and importers of large and small appliances. Its responsibilities include: (a) the establishment and management of the collection, transport, storage, recovery, treatment and control of WEEE and their packaging; (b) to assist the maintenance and enhancement of natural and energy resources through the collection, treatment and management of WEEE, as well as improving health conditions of citizens and the environment, and (c) the studies and research on the collection, transport, storage, recovery, treatment and control of such waste.

The collection process in which a CMS is involved can be described as follows (see Fig. 2): a CMS in particular establishes an agreement with a group of stores and collection points (or green points) to collect the electronic waste from a given category, for example white goods like refrigerators and washing machines. Every store has a given capacity (directly related to sales volume) to collect WEEE, usually associated to the selling of a new appliance. In turn, every store has allotted in its warehouse a certain space for WEEE collected. Whenever this space is about to be saturated, the store manager calls to the coordination call center so that these items be taken off by the corresponding depot. Each depot holds a heterogeneous fleet of capacitated vehicles, which are used in the collection of WEEE. Their activities include the collection of WEEE from stores, consolidation at the depot, and in some cases value-adding activities such as sorting and packaging. The WEEE collected by the depots are then consolidated and shipped to the disassembly plants, where the end-of-life appliances are dismantled.

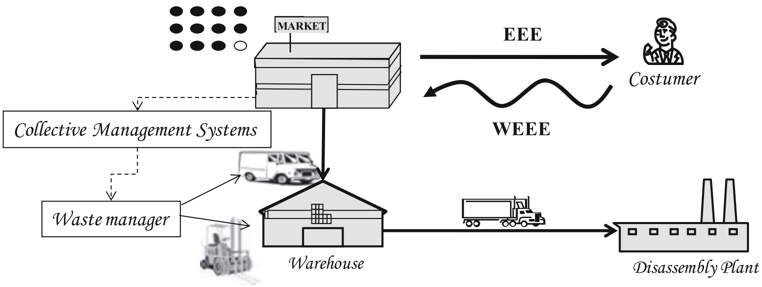

Fig. 2 The WEEE collection process

The WEEE collection problem consists of designing routes for the collection of end-of-life electronic goods. Vehicle routing models should consider that a fixed and heterogeneous fleet of capacitated vehicles with special features is used in the collection of WEEE from a set of customers. Each vehicle can at most perform a predefined number of trips without the given maximum operation time being exceeded. The amount of end-of-life items to be collected (hereafter referred to as the demand) of each customer can be greater than the capacity of the largest vehicle in the fleet. As a result the demand of a single customer may be split to be carried out by more than one route. Thus, each customer can be visited more than once on the same day. Collection orders to customers are triggered by a call from them. With each order there is an associated demand to be met and a range of dates within the collection should take place. This collection scheme is similar to the one used in the Netherlands for the collection of white goods (Beullens et al. 2004), and is characteristic of several reverse logistics systems.

Managers face two interrelated decisions: how to split the demand, and how to schedule the fleet of vehicles to fulfill collection orders. The truck-order assignment is the pairing of all collection orders to be fulfilled by the CMS one particular day and the trucks to which the orders are assigned. The assignment is made by a planner, who receives collection orders from the central coordination of the CMS and must assign these orders to trucks, while keeping transportation costs low and complying with several restrictions. In the temporal dimension the restrictions are expressed as date windows on the completion time of collecting servicing. Some date windows are soft and can be relaxed with an appropriate penalty cost. In Fig. 3 the problem structure of date windows is depicted. The planner knows which customers have active collection orders every day. Each active customer has associated an order demand, and an interval of days within the collection should take place (date window). Sometimes a time window constraint may be also imposed if some customers are allowed to deliver the end-of-life items just in some periods of time during a specific day. The planner also knows the truck fleet available to him, and is aware that some customers are located in narrow streets or in parts of the city where local ordinance forbids the entry of large trucks.

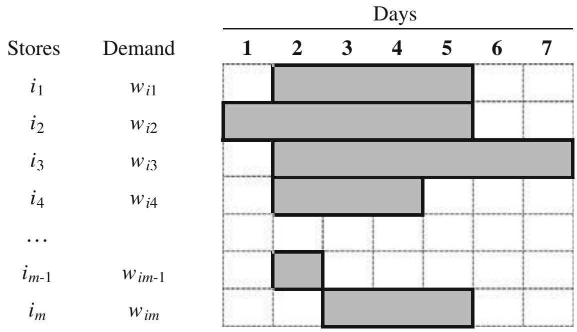

Fig. 3 Illustration of the concept of "date windows". The shadowed days show the dates of required collection for each store

From a theoretical point of view, the WEEE collection problem just described is characterized by four variants of the vehicle routing problem that have been independently studied in the logistics literature, including: (1) the use of a heterogeneous fleet of vehicles, (2) customers with high demand that may be split to fit the vehicle capacity, (3) the fact that a same vehicle may be assigned to more than one route, and (4) the agreement of a time interval for visiting customers. These characteristics make the problem complex and interesting, while complicating its classification within the standard VRP literature. The interested reader can find a complete analysis of the previous literature characterizing the problem addressed in this chapter in (Mar-Ortiz et al. 2011b).

The planning horizon for the WEEE collection problem is one week, and the schedule is updated every day. Since the problem is practically solved with a rolling horizon some collection orders are not always available when the problem is reoptimized. Some vehicles may also be unavailable because of maintenance operations. The demand of each customer is known in advance. Every customer has its own date window determined by its own policy. Managers want to minimize collection cost and to provide high quality service levels. The objective of the WEEE collection problem is usually minimizing the total routing cost.

2.1 Brief Literature Review

The Vehicle Routing Problem (VRP) is one of the most studied problems in the combinatorial optimization field and in the logistics literature. There are different variants of the VRP that can be characterized by the type of fleet, the number of depots, or the type of operations involved, among others. While, in recent years, there has been an increasing interest towards so-called rich VRP models that include important issues arising from real-world applications (Battarra et al. 2009), the literature on vehicle routing for reverse logistics is still very scarce. Even more, comparing the published literature between facility location issues and vehicle routing issues in reverse logistics, a considerable gap in vehicle routing for reverse logistics can be observed.

Most of the references address specific problems and case studies, for example (Schultmann et al. 2006) deal with the problem caused by the collection of plastic components of vehicles at the end-of-life phase in a closed-loop network in Germany. The problem is formulated as a symmetric VRP with backhauls, capacitated vehicles and maximum length tour constraints. The authors describe a tailored tabu search algorithm to generate a tour schedule at minimal cost. The problem of optimizing a closed-loop collection network for container vehicles in the Netherlands is described by (Blanc et al. 2006). The problem is formulated as a multi-depot VRP with simultaneous pickup and delivery in alternate locations. In a case study the metaheuristic approach TABUROUTE is applied for solving the design of WEEE collection routes in South Korea (Kim et al. 2009). On their own, the theoretical contributions found under the keywords vehicle routing in reverse logistics or collection routing, mainly deal with the vehicle routing problem with simultaneous pickup and delivery (Dell'Amico et al. 2006; Dethloff 2001).

From an algorithmic point of view, it is common to find implementations of heuristic algorithms to solve VRPs. In general, heuristic algorithms for routing problems consist of two phases: a tour construction procedure to generate an initial route, and an improvement procedure, which tries to find a better solution given an initial tour. Probably the best known, more discussed and analyzed heuristic procedure in literature is the constructive savings algorithm C&W (Clarke and Wright 1964). Since its publication, several variants and improvements have been proposed, some of them aimed at improving its computational efficiency through a use of better data structures, and other aimed at improving their effectiveness in terms of the quality of their solutions (Cordeau et al. 2007). For instance, (Mandl 1979) presents an extension of the original procedure to include a maximum number of nodes on a route and a maximum distance savings. As a result, the number of vehicles required to serve the demand points is also minimized. Starting from an initial solution, which may be determined using a constructive heuristic, the basic idea of local searches is to explore the neighborhood, i.e. a set of solutions in some sense close to the initial tour, to find a tour of better quality than the current one. Probably the most popular local search neighborhood in combinatorial optimization is the k-exchange neighborhood which for the TSP is usually referred to as k-opt. By combining these heuristics with intelligent search strategies, some efficient metaheuristic approaches have been developed over the last years. In (Toth and Vigo 2002) some of them are depicted.

Two of the main assumptions under which the classic VRP model is founded are the use of a homogeneous fleet of vehicles and the fact that the demand of each node is smaller than the capacity of the vehicles used. Note, however, that in the context of WEEE collection, both assumptions should be relaxed given the way in which these systems work, where the amount of WEEE generated by the collection point tends to be greater than the capacity of vehicles used in the harvesting, more over in WEEE collection systems a heterogeneous fleet of vehicles with special characteristics is frequently used. Of particular interest in the WEEE collection context are the contributions on the Heterogeneous Fleet Vehicle Routing Problem (HF-VRP) and Vehicle Routing Problem with Split Loads (VRP-SL). There are three variants of the HF-VRP, two of them relating to the number of vehicles of each type: limited or unlimited; and the third one refers to the accessibility restrictions of vehicles to customers. The vehicle routing problem with split loads (VRP-SL) was introduced by (Dror and Trudeau 1989) detailing its heuristic properties. They showed that the partition of loads may result in savings, for both the total travelled distances as well as in the number of vehicles used. By allowing the loads to be split, still better results may be obtained than those reached by the combined objective of minimizing the fixed costs of load and costs associated with the routes of vehicles.

2.2 The Case of Galicia, Spain

In the region of Galicia (settled in northwestern Spain, with a population close to 3 million inhabitants) more than 3,239 tons of WEEE were collected in 2008. Currently, the management of the recovery network is in charge of third-part-logistic service providers (3PL) recruited by the central coordination of the CMS, which are responsible for the logistics activities in each district. Their activities include the collection of WEEE from stores to a depot managed by each 3PL, consolidation at the depot, and in some cases value-adding activities such as sorting and packaging.

To complete the collection on the 707 stores and collection points that the CMS currently serves in Galicia, a network consisting of five depots is currently used (Fig. 4); such depots have been located and sized as a result of a historical evolution of the CMS relationships with their 3PL. From there, the items collected will be directly shipped to one of the two recovery plants, where they will be disassembled in its basic components, in order to remove the hazardous and polluting elements from those that can be recycled or reused. The CMS is now faced with the challenge to improve their collection activities to recover a larger proportion of WEEE at a reasonable cost and at the same time to meet the ever-increasing number of legislative requirements. Motivated by these facts, the central coordination of the CMS has considered changing its collection strategy, and optimizing its truck-order assignment process.

3 Mathematical Models

We consider two different formulations for the WEEE collection problem. The first is a modification of a site dependent formulation proposed by (Mar-Ortiz et al. 2011a). The second is an extension proposed by (Mar-Ortiz et al. 2011b) which considers date windows to handle a collection time interval schedule. Both models differ in the way the orders splitting scheme is approached.

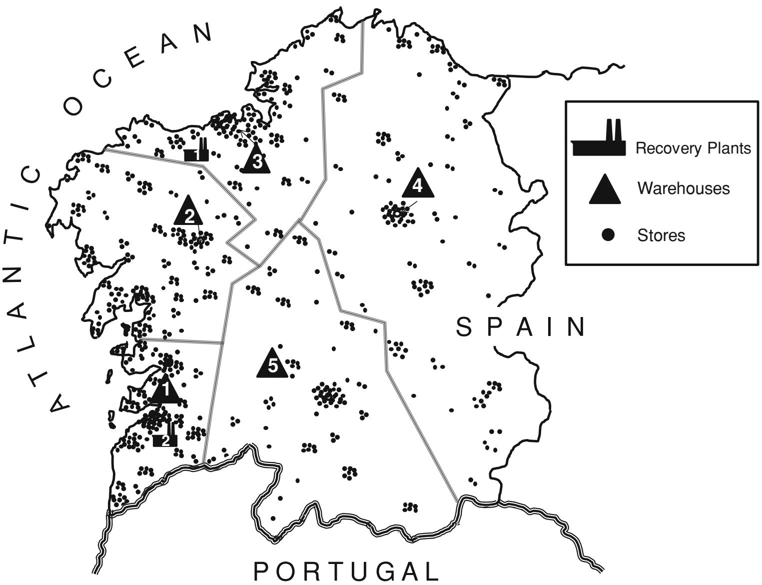

Fig. 4 Five regional depots in Galicia for WEEE collection and disposal

As mentioned in the literature review, a WEEE collection routing formulation must consider the use of a heterogeneous fleet of capacitated vehicles, and the fact that the amount of end-of-life items to be collected of each customer can be greater than the capacity of the largest vehicle in the fleet. Because of some customers are located in narrow streets or in parts of the city where local ordinance forbids the entry of large trucks, a site dependent restriction must also be imposed in the formulation. The first formulation (VRPHFSD) takes into account the heterogeneous fleet and the site dependent conditions, but it does not consider the split collection scheme. However, this model can be widely applied in situations where the order's splitting is made by a planer, who receives the collection orders from the CMS and must assign these orders to trucks, while keeping transportation costs low. On the other hand, the second formulation (VRPSLDW) proactively incorporates a split order's condition.

3.1 Heterogeneous Fleet and Site Dependent Formulation

Formally speaking this mathematical formulation requires the definition of a directed graph $G = (V, A)$ where $V = \{v_0, v_1, \ldots, v_m\}$ is a set of vertices, and $A = \{(v_i, v_j): i \neq j\}$ is a set of arcs. Vertex v_0 denotes the depot at which a heterogeneous fleet of capacitated vehicles has been allotted, while the remaining m vertices of V represent the customers to be visited. With every customer there is associated a demand w_i. For every arc the distance $d_{(i,j)}$ is known. For each vehicle k we know the maximum load capacity, the set of customers that vehicle k may visit (because street access restrictions), and the variable travelling cost. The problem consist of designing a set of least cost vehicle routes in such a way that every route starts and ends at the depot, and every customer $V\setminus\{v_0\}$ is visited exactly once by exactly one vehicle. The input data are:

- V: set of vertices, representing the union of all stores allotted to the depot plus the depot itself, and card $(V) = m + 1$;
- A: set of directed arcs (v_i, v_j) and card $(A) = n$;
- K: set of vehicles allotted to the depot;
- w_i: amount of items deliver by customer i (demand) every time it is visited;
- Q_k: capacity of vehicle k;
- λ_k: travelling cost per kilometer for vehicle k (includes fixed and variable cost per kilometer travelled);
- $d_{(i,j)}$: distance associated with every arc $(i, j) \in A$, representing the traveling time required to move from customer i to customer j.

The model also uses the following variables and sets:

- $K(i) \subseteq K$:subset of vehicles allowed for customer i;
- $x^k_{(i,j)} \in \{0, 1\} \quad (i,j) \in A, k \in K : x^k_{(i,j)} = 1,$ if and only if arc (i, j) is transversed by vehicle k;
- $u^k_j \in \Re \quad j \in V\setminus\{0\}, k \in K$:cumulative load in vehicle k after visiting customer j.

The model can then be formulated as follows:

$$\text{minimize} \sum_{(i,j)\in A} \sum_{k\in K} \lambda_k \cdot d_{(i,j)} \cdot x^k_{(i,j)} \tag{1}$$

Subject to:

$$\sum_{k\in K(j)} \sum_{i\in V\setminus\{j\}} x^k_{(i,j)} = 1 \quad \forall j \in V\setminus\{0\} \tag{2}$$

$$\sum_{j\in V\setminus\{0\}} \sum_{k\in K(j)} x^k_{(0,j)} = \sum_{i\in V\setminus\{0\}} \sum_{k\in K(i)} x^k_{(i,0)} \tag{3}$$

$$\sum_{i\in V\setminus\{j\}} x^k_{(i,j)} = \sum_{i\in V\setminus\{j\}} x^k_{(j,i)} \quad \forall j \in V, k \in K(j) \tag{4}$$

$$u^k_j \geq M + w_j + M \cdot \left(x^k_{(0,j)} - 1\right) + \sum_{i\in V\setminus\{0\}:i\neq j} w_i \cdot x^k_{(i,j)} \quad \forall j \in V\setminus\{0\}, k \in K(j) \tag{5}$$

$$u^k_j \geq u^k_i + w_j + \hat{M} \cdot \left(x^k_{(i,j)} - 1\right) + \left(\hat{M} - w_i - w_j\right) \cdot x^k_{(j,i)} \quad \forall i,j \in V\setminus\{0\} : i \neq j, k \in K \tag{6}$$

$$u_i^k \geq M + \sum_{j \in V \setminus \{0\}: j \neq i} w_j \cdot x_{(j,i)}^k K \quad \forall i \in V \setminus \{0\}, k \in K(i) \tag{7}$$

$$u_i^k \leq M + Q_k - \sum_{j \in V \setminus \{0\}: j \neq i} w_j \cdot x_{(i,j)}^k \quad \forall i \in V \setminus \{0\}, k \in K(i) \tag{8}$$

$$x_{(i,j)}^k \in \{0, 1\} \quad \forall (i,j) \in A, k \in K \tag{9}$$

The objective of the problem is the transportation of the WEEE collected from the origins (stores) to the destinations (depots) through the most economic routes. Based on the transportation requirements several routing problems may emerge. The objective function Eq. (1) minimizes the total collection cost, composed of routing costs between visited customers by vehicle k in all routes. Equation (2) ensures that vertex j can be reached directly just from a single vertex $i \neq j$, with a single vehicle k capable of accessing vertex j. Equation (3) guarantee that the number of tours leaving the depot is equal to the number of tours arriving to depot. Equation (4) establishes the continuity conditions and ensures that the vehicle arriving to a given vertex is the same vehicle leaving such vertex. It should be noted that inequalities Eq. (5–8) are variations of the sub-tour elimination constraints, which were lifted following the procedure described by (Desrochers and Laporte 1991; Kara et al. 2004) to replace weaker requirements. Equations (5) and (6) establish the heterogeneous fleet capacity conditions and sub-tour elimination constraints, where $M = 1 + \Sigma_{i \in V} w_i$ and $\hat{M} = M \times 1000$. Equation (5) was chosen to replace the weaker requirement $u_j^k \geq M + w_j$, if $x_{(0,j)}^k = 1$ for all $j \in V \setminus \{v_0\}$, $k \in K$. Equation (6) is a modification of the capacity cut constraints allowing the existence of stores with a greater demand than the capacity of the smaller vehicle type used. This constraint was chosen to replace the weaker requirement $u_j^k \geq u_i^k + w_j$ if $x_{(i,j)}^k = 1$ for all $j \in V \setminus \{v_0\}$, $k \in K$. Equations (7) and (8) provide the lower and upper bounds for the variable u_i^k, which together with constraint in Eq. (4) enforces the tour to end at the depot when the inclusion of some other vertex in the tour exceeds the capacity of vehicle k. Equations (7) and (8) replace the weaker requirements $M \leq u_i^k \leq M + Q_k$ for all $i \in V \setminus \{v_0\}$, $k \in K$. This formulation differs from the heterogeneous vehicle routing problem formulations presented by (Yaman 2006), and enclose $\{2\ K\ (n^2 + n–1) + n\}$ constraints.

3.2 Split Loads and Date Windows Formulation

In (Mar-Ortiz et al. 2011b) a mathematical formulation for the Vehicle Routing Problem with Split Loads and Date Windows (VRPSLDW) is proposed, which requires the definition again of a directed graph $G = (V, E)$ where $V = \{v_0, v_1, \ldots, v_m\}$ is a set of vertices, and $A = \{(v_i, v_j): i \neq j\}$ is a set of arcs connecting the vertices. Vertex v_0 denotes the depot where a heterogeneous fleet of $K = \{1, \ldots, k\}$ vehicles with capacity Q_k has been allotted, while the remaining m vertices of V represent the customers to be visited. For every arc $(i, j) \in A$ the distance $d_{(i,\ j)}$ is known. For each vehicle k we know the maximum load capacity, the set of customers that vehicle k may visit (because of street access restrictions), and the variable travelling cost of vehicle k. For the collection, the independent customers make use of a call system with a timely collection guarantee. Each collection order predefines the quantity of items w_i to be collected from customer i and the range of dates within which the collection should take place. The time interval to carry out the collection from a single customer is specified by its date window $[s_i, f_i]$, where s_i and f_i are respectively the first and last days within which the collection must take place, such that $s_i \leq f_i$. For all customers the service time μ_i is assumed to be constant, since each customer is usually served in a full truck load, being visited when it has at hand a sufficient number of items to be collected. For the sake of real practice, when the number of items to be collected from any customer i is less than a constant factor ε, those items are not collected and are labeled as backorders to be considered in a following request. The input data are:

- V: set of vertices, representing the union of all stores allotted to the depot plus the depot itself, and card$(V) = m + 1$;
- A: set of directed arcs (v_i, v_j) and card$(A) = n$;
- T: set of days in the planning horizon, $t = 1, \ldots, T$;
- K: set of available vehicles, $k = 1, \ldots, K$;
- w_i: amount of items to be collected (demand) at customer $i \in V \backslash \{0\}$;
- ε: minimum load to be collected at any customer i, to justify its visit;
- $d_{(i,\ j)}$: travelling distance (km) associated with every arc $(i, j) \in A$;
- $t_{(i,\ j)}$: travelling time (hrs) associated with every arc $(i, j) \in A$;
- μ_i: service time (hrs) at vertex $i \in V \backslash \{0\}$;
- Q_k: capacity of vehicle k;
- L_k: maximum operation time for vehicle k per day;
- λ_k: travelling cost per kilometer for vehicle k;
- R: maximum number of trips that any vehicle may perform per day.

The model also uses the following variables and sets:

- $K(i) \subseteq K$:subset of vehicles allowed for customer i;
- $T(i) = \{t : s_i \leq t \leq f_i\} \subseteq T$:subset of days within customer i must be visited.
- $y_{ij}^{(tkr)} \in \{0, 1\} \quad (i,j) \in A, t \in T, k \in K, r \in R : y_{(i,j)}^{(tkr)} = 1$, if and only if arc (i,j) is transversed by the trip r of vehicle k on day t. In this sense, a route is defined by a set of three attributes (tkr).
- $x_i^{(tkr)} \in Z_+ \quad i \in V, t \in T, k \in K, r \in R : x_i^{(tkr)} = 1$, amount of items collected at customer i on route (tkr).
- $\sigma_i \in Z_+ \quad i \in V : x_{ij}^{(tkr)} = 1$, amount of items not collected from customer i, due to its economical infeasibility.
- $u_i^{(tkr)} \in \Re \quad i \in V, t \in T, k \in K, r \in R$: cumulative load in route (tkr) after visiting customer i.

The optimization problem is to determine which customers are served by each vehicle, what route the vehicle will follow to serve those customers assigned and how much demand each vehicle will collect from each customer, while minimizing the routing cost. The mathematical model for the VRPSLDW can then be formulated as follows:

$$\text{minimize} \sum_{(i,j)\in A} \sum_{t\in T} \sum_{k\in K} \sum_{r=1}^{R} \lambda_k \cdot d_{(i,j)} \cdot y_{(i,j)}^{(tkr)} \tag{10}$$

Subject to:

$$\sum_{i\in V\backslash\{j\}} \sum_{r=1}^{R} y_{(i,j)}^{(tkr)} \le 1 \quad \forall j \in V\backslash\{0\}, t \in T(j), k \in K(j) \tag{11}$$

$$\sum_{j\in V\backslash\{0\}} y_{(0,j)}^{(tkr)} \le 1 \quad \forall t \in T, k \in K, r = 1,\ldots,R \tag{12}$$

$$\sum_{i\in V\backslash\{j\}} y_{(i,j)}^{(tkr)} = \sum_{i\in V\backslash\{j\}} y_{(j,i)}^{(tkr)} \quad \forall j \in V, t \in T(j), k \in K(j), r = 1,\ldots,R \tag{13}$$

$$x_j^{(tkr)} \le w_j \cdot \sum_{i\in V\backslash\{j\}} y_{(i,j)}^{(tkr)} \quad \forall j \in V\backslash\{0\}, t \in T(j), k \in K(j), r = 1,\ldots,R \tag{14}$$

$$x_j^{(tkr)} \ge \varepsilon \cdot \sum_{i\in V\backslash\{j\}} y_{(i,j)}^{(tkr)} \quad \forall j \in V\backslash\{0\}, t \in T(j), k \in K(j), r = 1,\ldots,R \tag{15}$$

$$y_{(i,j)}^{(t,k,r)} \ge y_{(i,j)}^{(t,k,r+1)} \quad \forall i,j \in V\backslash\{0\}, t \in T, k \in K, r = 1,\ldots,R-1 \tag{16}$$

$$\sum_{t\in T(i)} \sum_{k\in K(i)} \sum_{r=1}^{R} x_i^{(tkr)} + \sigma_i = w_i \quad \forall i \in V\backslash\{0\} \tag{17}$$

$$\sum_{(i,j)\in A} \sum_{r=1}^{R} \left(t_{(i,j)} + \mu_j\right) \cdot y_{(i,j)}^{(tkr)} \le L_k \quad \forall t \in T, k \in K \tag{18}$$

$$u_j^{(tkr)} \ge u_i^{(tkr)} + x_j^{(tkr)} + Q_k \cdot \left(y_{(i,j)}^{(tkr)} - 1\right) \quad \forall i,j \in V\backslash\{0\} : i \ne j, t \in T, k \in K, r = 1,\ldots,R \tag{19}$$

$$x_i^{(tkr)} \le u_i^{(tkr)} \le Q_k \quad \forall i \in V\backslash\{0\}, t \in T(i), k \in K(i), r = 1,\ldots,R \tag{20}$$

$$x_i^{(tkr)} \ge 0, u_i^{(tkr)} \ge 0, 0 \le \sigma_i \le \varepsilon - 1 \quad \forall i \in V, t \in T, k \in K, r = 1,\ldots,R \tag{21}$$

$$y_{(i,j)}^{(tkr)} \in \{0,1\} \quad \forall (i,j) \in A, t \in T, k \in K, r = 1,\ldots,R \tag{22}$$

The objective function Eq. (10) minimizes the total routing cost in all journeys made by the fleet of vehicles. Equations (11–13) provide the connectivity and continuity constraints. Equation (11) states that a customer j can be reached directly just from a single customer $i \neq j$, on a trip r of a feasible route (t, k, r). In this sense, a route is defined by a set of three attributes: the day t, the vehicle k and the trip r. Equation (12) guarantees that each route (t, k, r) may be performed just once at most. Equation (13) establishes the continuity conditions and ensures that the vehicle k arriving at a given customer j in its trip r in day t, is the same vehicle leaving such a customer. Equations (14) and (15) specify the collection bounds for each customer on any route. Equation (14) states that the amount of items collected from a customer j by route (t, k, r) does not exceed the customers' demand, whilst Eq. (15) provides that at least a constant factor of ε items must be collected by a given route leaving the depot. Equation (16) guarantees the proper use of trips in every route. It establishes that every day the trip r of a vehicle k must be performed before its trip $r + 1$. Moreover, constraints (Eqs. 15 and 16) strengthen the formulation by restricting duplicate solutions, which reduce the number of nodes in the branch-and-bound tree. Equation (17) ensures the collection of a customer's demand in one or more routes, or its consideration as a backorder. Equation (18) sets the maximum service time for each vehicle, whereas Eqs. 19 and 20 provide both the capacity restrictions and the sub-tour elimination constraints. Finally, Eqs. 21 and 22 deal with the nature of the decision variables. Note that although $x_i^{(tkr)}$ and σ_i are declared as continuous, the formulation forces them to take integer values.

4 Solution Approaches

For small instances, both integer linear programming formulations of Sect. 3 can be solved by a commercial MIP solver. From a computational point of view, VRPHFSD is better than VRPSLDW in that it can solve larger instances. However, neither model can be used for the optimal solution of instances of realistic size. The VRPSLDW formulation is in a sense more interesting than VRPHFSD since it can easily lend itself to the development of heuristics. Furthermore, it can be easily extended to consider other practical constraints. However, in this chapter we concentrate on heuristic approaches.

We have previously developed two heuristic algorithms for solving the WEEE collection problem: a three-stage heuristic procedure capable of managing a heterogeneous fleet of capacitated vehicles, which is based on the savings algorithm (see Mar-Ortiz et al. 2011a); and a GRASP based algorithm for solving the VRPSLDW (see Mar-Ortiz et al. 2011b). There are many ways in which both algorithms can be improved so that the number and length of tours needed to reach quality levels can be reduced, thus making its application to larger problem instances feasible. For example, by local optimization heuristics like 2-opt, 3-opt, GENUIS or Lin-Kernighan procedures. In this chapter both algorithms have been

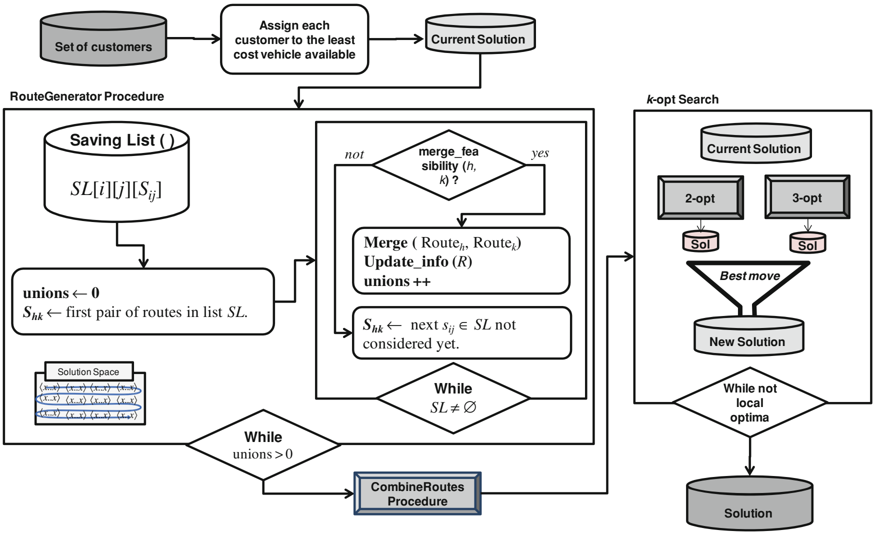

Fig. 5 Enhanced Savings algorithm for the VRPHFSD

enhanced by embedding a k-opt procedure ($k = 2$, 3) aiming to improve the performance of long routes. This is a standard approach to improve efficiency of general purpose algorithms for vehicle routing problems.

The k-opt neighborhood can be defined by: $N_k\ (T) = \{T' \mid \rho\ (T, T') = k, T' \in T\}$. This definition introduces a whole set of search neighborhoods parameterized by k. The size of each neighborhood N_k for a given instance is dependent on the instance size n and the chosen parameter k and is equal to $C\ (n,\ k)$. In order to perform a move from a tour T to a neighboring tour $T' \in N_k$, first k distinct edges of T are removed and T broken into k tour segments. These tours segments are reconnected to form a tour T' by inserting k edges. 2-opt represents the smallest and simplest of the k-opt search neighborhoods of the TSP. The basic idea is to remove two edges in the current tour, breaking it into two segments. The tour is then restored by reconnecting these sequences in the unique possible fashion. A natural expansion of the 2-opt neighborhood is given by 3-opt. As the name suggests, here up to 3 edges in the current tour are removed and the resulting three tour segments afterwards reconnected. In contrast to 2-opt where there exists only one possible way to reconnect the broken tour, in the case of 3-opt there exist 8.

The savings based algorithm described by (Mar-Ortiz et al. 2011a) is a three-stage heuristic procedure capable of managing a heterogeneous fleet of capacitated vehicles (see Fig. 5). The first stage of the heuristic is analogous to the C&W algorithm. In the second stage, the purpose of the Routes Generator procedure is to construct a set of feasible routes, analyzing when required, the feasibility of using a different vehicle type for merging two different routes. A route is feasible if the capacity of the vehicle along the route is not exceeded, and the change in the use of

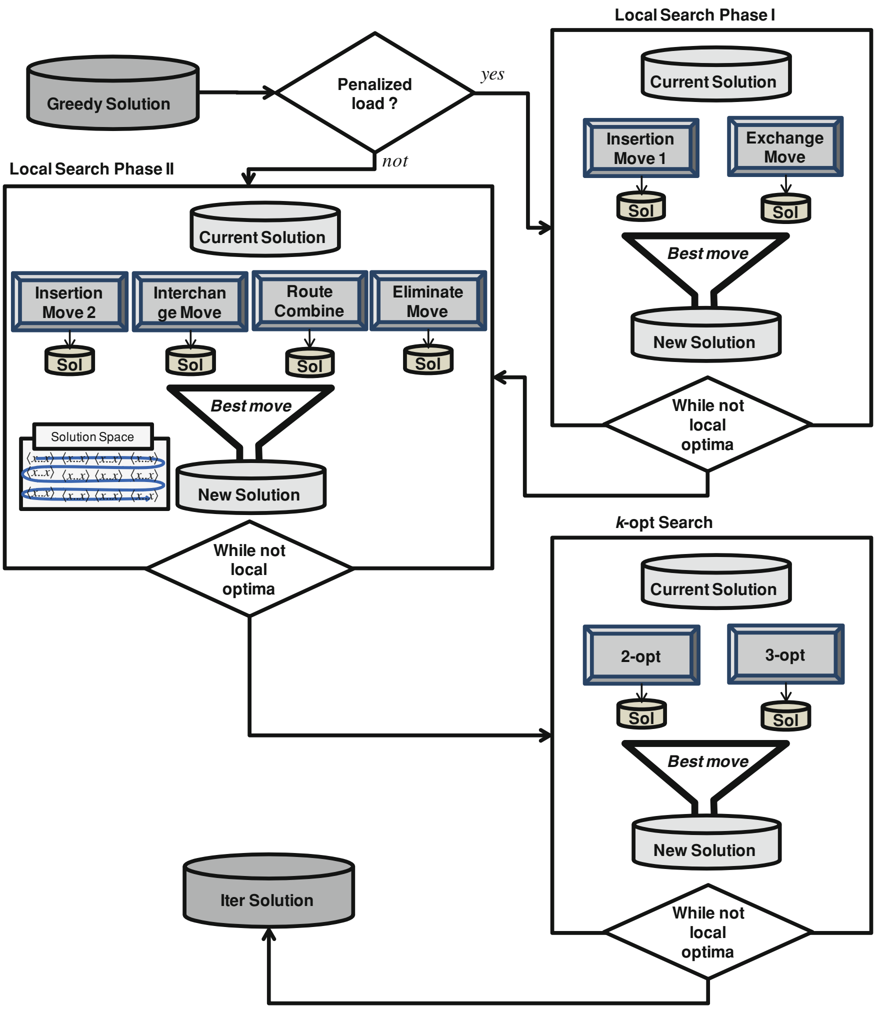

Fig. 6 Enhanced GRASP algorithm for the VRPSLDW

a different vehicle type is feasible if when combining two routes: the new vehicle can access to all stores in both routes and using such new vehicle is less expensive than using both routes in their own. The authors make use of a recursive function implementation for the systematic generation of routes. If the union of at least a couple of routes was feasible, the algorithm updates the saving list and repeats the procedure, otherwise, proceed with the combination of routes. In the third stage, the Combine Routes procedure determines the set of routes that one vehicle can serve in a given period, trying to optimize the number of trucks required to serve the routes. Finally, the *k*-opt procedure is implemented aiming to improve the performance of longer tours, and we obtain the final heuristic solution.

A GRASP algorithm is composed of two mechanisms: a greedy randomized construction mechanism, and a local search mechanism. In (Mar-Ortiz et al. 2011b) the construction mechanism at each iteration aims to allocate the largest amount of unsatisfied demand from customer i to a single route π such that π is feasible, unrestricted and non-penalized for customer i. The basic principle for the construction phase aims to fulfill the routes as much as possible and split the demand as little as possible. The constructive procedure starts with an empty solution, and the customers demand is iteratively distributed among the routes according to the greedy randomized construction scheme. When the total demand of each customer has been distributed among the routes or the pending demand to assign of each customer is smaller than a value ε, the constructive phase finishes and the local search procedure is initiated. The local search procedure is carried out by manipulating the allocation of the portion of demand in the LOAD matrix and updating the routes involved in ROUTE. This procedure is made up of two phases. Phase I verifies if penalties exist by serving the customers on a penalized route, and seeks to eliminate them. Phase II explores four neighborhoods of the solution space in order to reduce the routing costs. We improve this algorithm by embedding a k-opt search strategy after the local search Phase II in order to get a solution for a GRASP iteration (see Fig. 6).

5 Computational Experiments

Both algorithms have been proved to give good results on solving WEEE collection routing problems. In this section we present the experimental results obtained with an implementation of both algorithms. The heuristics were coded in C using the Microsoft Visual C++ 6.0 programming environment via the Windows Vista operating system. All experiments were conducted on an Acer AMD Athlon X2 PC with a processor operating at 1.90 GHz and 2.00 GB RAM. The aim of the experiment is to compare the performance of both algorithm approaches on solving different problem instances in order to gain insights into the routing strategies issues. To do it so we first describe how realistic test instances were obtained, and we then provide results attained with both algorithms.

5.1 Validation of the Heuristics

Previous computational results indicate that both algorithms satisfactorily handle real-life problems as well as other random instances generated. The savings-based algorithm has shown a good performance: on average the heuristic solution obtained is at 1.18% from the best solution found. In less than 0.5% of the instances a deviation greater than 7% was obtained; however in 80% of the instances the deviation was lower than 2.50%, it was possible to achieve the optimal value in 23.33% of the instances generated. In fact, for many instances the algorithm was able to reach better solutions in less than one second, than a commercial MIP solver after hours of computation. It was not possible to determine any negative trend in the algorithm performance, as a result it is expected a similar behavior in larger instances, such as those commonly found in real situations.

For the GRASP algorithm, experimental results on a set of 540 random instances generated show its convenience to solve problems in which the date window and the collection capacity are tightly constrained. These kinds of problems are commonly found in real situations. As a result, a good behavior in real problems is expected. The performance of the metaheuristic algorithm was analyzed with respect to the amount of processing time required by the procedure to generate a solution and the quality of the solutions. The results of the ANOVA test showed that factors like the date windows and the capacity tightness regarding demand are statistically significant for the algorithm performance. On the other hand, it cannot be demonstrated that a factor like the dispersion of the customers affects the quality of the solutions obtained, which is a sign of the robustness of the algorithm to deal with this kind of problems. Results from the local search analysis indicate that the local search indeed provides considerably improved solutions. Especially relevant are the phase I local search moves which were able to reduce infeasibilities in all cases. Finally, the comparison of the proposed approach with current practice reveals that transportation costs fall an average of 15.96% from the current levels.

5.2 Data Instances

In order to test both algorithms on real-world instances of the WEEE collection problem, we obtain new instances from the CMS operating in Galicia. For each depot the total amount of items collected per week are recorded. Data related to the fleet of vehicles used in the collection process, distances and travel times, as well as the real amount of items collected in every store, are based on previously published researches. In general, two types of vehicles with different load capacities 15 and 25 items) are used in the collecting process. The first (hereafter referred to as vehicle type 1) are smaller than the corresponding vehicles with a load capacity of 25 items (hereinafter referred to as vehicle type 2). They therefore can access to all stores, although the latter have a loading platform that facilitates the collection task. Annual fixed costs are respectively 34,993.47 and 41,723.96 €/year, while the variable costs reach 0.15 and 0.17 €/km.

For the experimental study, we created five instance sets (one for each depot). For each depot we randomly selected 10 weeks within the 2008, resulting in 50 instances with a different number of customers, demand type, date windows tightness, capacity tightness regarding demand, and dispersion of customers (see Table 2).

Table 2 Input Data

Instance set	Number of items and (trips) to each plant per year		Number of stores served per week	Range of weekly demand collected
	Plant 1	Plant 2		
Mos1	5300 (53)	7933 (80)	92–166	260–921
San2	11395 (114)	–	47–175	520–1478
Ole3	13550 (136)	–	87–128	331–1059
Lug4	10700 (107)	–	60–136	254–1147
Carb5	4100 (41)	6144 (62)	56–102	226–829

Table 3 Best, average and worst relative deviation from best known solutions (BEST) obtained by three solution approaches

Instance set	Current practice			Savings-based			GRASP		
	Bst.	Avg.	Wrt.	Bst.	Avg.	Wrt.	Bst.	Avg.	Wrt.
Mos1	5.51	18.51	30.19	1.54	4.00	6.99	0.00	2.33	4.99
San2	5.09	16.84	20.78	0.00	0.30	0.49	0.00	0.00	0.00
Ole3	9.92	20.47	33.90	0.21	3.13	7.11	0.00	4.07	5.11
Lug4	13.20	20.25	24.47	0.42	2.25	6.25	0.00	0.00	0.00
Carb5	11.09	16.74	29.16	0.33	2.25	3.29	0.00	0.00	0.00

5.3 Results and Analysis

In the computational experiment we are interested in comparing both heuristic approaches with current practice. To compare the performance of the three methods more directly, we estimated the transportation cost of each method. To measure the difference between the solutions found by each method and the best known solution found so far (hereafter referred to as BEST), the relative deviation (DEV) is computed as $((\delta_{\mathrm{HEU}}-\delta_{\mathrm{BEST}})/\delta_{\mathrm{BEST}}) \times 100$, where δ_{BEST} and δ_{HEU} are the BEST and heuristic solutions respectively. It should be noted that the GRASP parameters were set on iters $= 100$ and $\alpha = 0.5$.

Current practice. The field data were analyzed to estimate the transportation cost of the current delivery method from stores to the corresponding regional depots. The datasets employed contained only the number of items collected each day from each store for the corresponding regional depot, and they did not specify the types of trucks or the number of trucks that were used. Additionally, the records did not include specific cost information. Hence, some assumptions to estimate the cost were made, reflecting the current standard for routing and scheduling WEEE collection activities. From the records, the number of items was transformed to the type and number of trucks that might be used. We assume that type 1 trucks were used, and based on the analysis of current practices, this assumption appears valid. We assume that, whenever possible, a full truck load was used, and we also attempted to minimize the number of trucks used. In other words, routes are optimized based on the known supply of end-of-life electronic items from each store. After the number of tours was estimated, we calculated the distances of the entire tours by multiplying the two-way distance from each store to the corresponding regional depot.

Results. Table 3 shows the best, average and worst percentage deviation from BEST for each of the three methods being compared. We can see that, the GRASP method out performs the other two methods including our Savings-Based algorithm. However, our Savings-Based algorithm requires shorter running times to reach quality solutions. The Savings-Based method requires shorter running times to reach solutions (on average 2.38% from BEST), but the worst solution found yields to 7.11% from BEST, while the GRASP algorithm is on average 1.28% from BEST and the worst solution found is below 5.11% from BEST. In all cases our heuristic procedures are able to find better solutions than the current practice. On the average, GRASP solutions obtained are above 2% better than the Savings-Based solutions. In only eight instances a deviation greater than 4% was obtained. In thirty-eight instances the GRASP solutions were quite better than the other solutions.

The application of each method results on a different number of routes and length characteristics. For example, by applying the Savings-Based heuristic procedure all over the five sets, 1638 routes were generated totaling 161,060.62 km. The number of routes per set and the number of kilometers traveled between the corresponding areas remain almost constant. The distance traveled in each set provides information on two parameters: the size of territory to be covered by the depot, and the number of stores, thus characterizing the differences between the five regions (sets). By applying the GRASP algorithm both the number of routes and the kilometers traveled were considerably reduced. Nor it was possible to determine any relationship between the number of tours and the number of customers in a set. A similar situation is presented when assessing the annual distance travelled by the vehicles allotted to each instance in combination with the specific costs of transportation. Results indicate that both the appropriate use of vehicles and a suitable splitting of loads is a determinant factor in the performance of any WEEE collection system.

6 Conclusions and Further Research

This chapter describes the WEEE collection problem. Given its complexity, heuristic algorithms are required developed to solve the related collection routing problems. We have provided two mathematical formulations for it and we have enhanced two previously published heuristics by embedding into them a *k*-opt procedure aiming to improve longer routes. Fifty real-world instances were solved to test the efficacy of both algorithms on solving instances of realistic size and to derive efficient vehicle routing practices for WEEE collection. Computational results using field data show that the proposed algorithms outperform the existing method in Galicia. The further research will include the design of a decision support system for routing and scheduling decision in WEEE collection.

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Impact of Emerging Environmental Regulations on the Reverse Logistics System for Portable Batteries in Spain

Eva Ponce-Cueto and José A. González-Manteca

Abstract The main aim of this chapter is to analyse the impact of the emerging environmental regulation of batteries on the Spanish reverse logistics system. The complex reverse supply chains for collecting, recovering and treating used batteries will be characterised in the Spanish context. The main problems regarding this system will be identified, and, finally, improvements to the current reverse logistics system will be proposed.

Keywords Reverse logistics · Portable batteries · Collection

1 Introduction

The generation of electronic waste is currently an important problem in modern society. In Europe, annual quantities of Waste of Electrical and Electronic Equipment (WEEE) are estimated to be on the order of 8.3 million tonnes (WEEE Forum 2010). One source of WEEE is batteries, which supply energy to many

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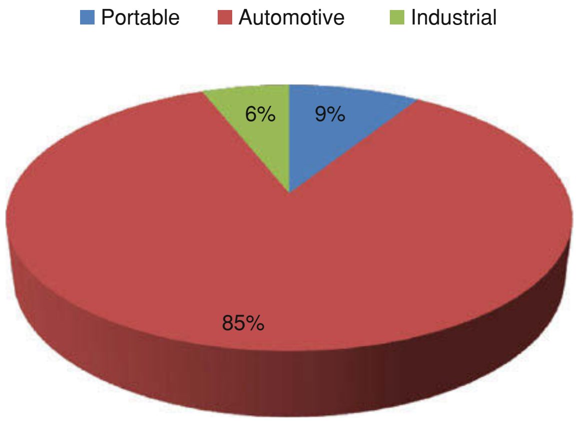
Fig. 1 Spanish market share of batteries in 2010. Source Spanish Ministry of Industry, Tourism and Trade (2011)



types of portable electric and electronic devices, such as telephones, radios, computers, mobile phones, and even electric and hybrid cars.

More than 40 billion batteries are sold worldwide per year. Given this situation, countries must decide what to do with billions of spent batteries containing millions of tonnes of toxic and hazardous compounds. As a legal response to this problem, the European Union has issued regulations for electrical and electronic equipment waste (European Union 2002) and, more specifically, for spent batteries (European Union 2006b). All of the EU Member State producers have been required to organise the collection and environmentally sound management of batteries since 2008 (Directive 2006/66/EC). A selective collection system is needed, and the collected waste batteries should be treated properly. The Directive quantifies recycling targets for collected carbon-zinc and alkaline waste batteries and establishes a recycling rate of 50% for consumer waste batteries by 2015.

According to the Kg sales in Spain in 2010, the Spanish market of batteries can be categorised according to three types (portable, automotive, and industrial) as is shown in Fig. 1:

This study focuses on portable batteries. Automotive and industrial batteries and accumulators are beyond the scope of this study. Among portable batteries, there are different types: button cell, standard batteries, portable accumulator and other types (not automotive, not industrial). Figure 2 shows the percentages of each type that are sold in Spain. Standard batteries include alkaline, lithium non-rechargeable and carbon-zinc batteries. Button cells include lithium, mercuric oxide, manganese oxide, silver oxide and zinc.

The main goal of this chapter is to analyse the impact of the emerging environmental regulation of batteries on the Spanish reverse logistics system (automotive batteries and accumulators are beyond the scope of this study). The complex reverse supply chains for collecting, recovering and treating used batteries will be characterised in the Spanish context. The main problems regarding this system will be identified, and, finally, improvements to the current reverse logistics system will be proposed.

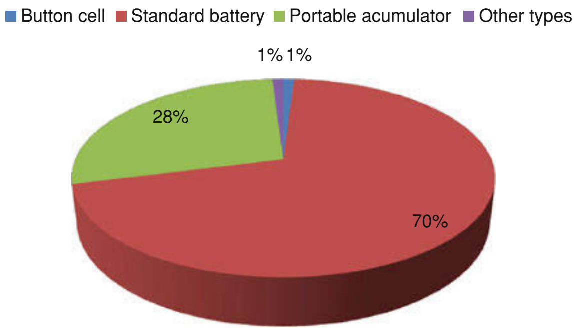


Fig. 2 Types of portable batteries sold in Spain in 2010. Source Spanish Ministry of Industry, Tourism and Trade (2011)

2 Emerging Environmental Regulation of Batteries

The most recent European regulation regarding batteries is the Directive 2006/66/EC of the European parliament and of the council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC.

Other Directives related to this waste are the following:

- Council Directive 91/157/EEC of 18 March 1991 on batteries and accumulators containing certain dangerous substances.
- Council Directive 78/319/EEC of 20 March 1978 on toxic and dangerous wastes; this directive requires carefully regulating the activities of producers and managers of these wastes.
- The generic Directives of wastes are the following:
- Directive 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste and the repealing of certain Directives.
- Directive 2006/12/EC of the European parliament and of the council of 5 April 2006 on waste.

The Electrical and Electronic Equipment Waste Directive are as follows:

- Directive 2003/108/EC of the European parliament and of the council of 8 December 2003, which amended Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). This Directive covers all of the electrical and electronic equipment used by consumers, and the electrical and electronic equipment intended for professional use. This Directive applies without prejudice to the Community legislation on safety and health requirements that protects all of the actors that are in contact with WEEE as well as specific community waste management legislation, most specifically the Council Directive 91/157/EEC of 18 March 1991 on batteries and accumulators containing certain dangerous substances. The aim of this Directive is to reduce the quantity of these wastes and the danger posed by their compounds. In case that this equipment includes batteries, the batteries would be considered to be part of the equipments, implying a corresponding responsibility for the producer (Table 1).

Table 1 European Union regulation related to spent batteries

Year	Code	Topic
1978	78/319/EEC	Establishes community rules on the disposal of dangerous waste.
1991	91/157/EEC	Focuses on the recovery and controlled disposal of those spent batteries and accumulators containing certain dangerous substances
2002	2002/96/EC	Seeks the prevention of waste electrical and electronic equipment (WEEE), and, in addition, the reuse, recycling and other forms of recovery of such wastes to reduce the disposal of the waste. This Directive also seeks to improve the environmental performance of all of the operators involved in the life cycle of the electrical and electronic equipment.
2003	2003/108/EC	This Directive covers all of the electrical and electronic equipment used by consumers and electrical and electronic equipment intended for professional use.
2006	2006/12/EC	A general framework to prevent or reduce waste production and its harm. It advises to establish an integrated and adequate network of disposal installations.
2006	2006/66/EC	Applies to all of the types of batteries and accumulators regardless of their shape, volume, weight, material composition or use. Establishes specific rules for the collection, treatment, recycling and disposal of waste batteries and accumulators to supplement relevant Community legislation on waste and to promote a high level of collection and recycling of waste batteries and accumulators.
2008	2008/98/EC	Revised Waste Framework Directive. Introduces the concept of the end of waste by which selected waste streams could cease to be considered to be waste if they comply with the end of waste criteria. Establishes the need for having waste management plans.

All previous directives have been transposed into Spanish law

3 Spanish Legislation

The transpositions of the above regulations have resulted in the following decrees:

- Royal Decree 833/1988 of 20 July, which approves Regulations for the implementation of the Law 20/1986. Basic Toxic and Hazardous Waste. Incorporated into national law Directive 78/319/EEC of 20 March relating to such waste. This Decree requires careful regulation and control of the activities of the producer and manager to ensure adequate treatment and control intended to achieve safety in the environment and population.
- Law 10/1998 of 21 April on wastes. The main aim of this law is to establish a common standard for all of the types of wastes. In addition, each waste will be covered by specific regulations. Another important issue is the delegation to the Spanish autonomous communities (17 regions) of environmental responsibilities

Table 2 Spanish regulation for spent batteries

Year	Decree	Topic
1988	RD 833/1988	Basic Toxic and Hazardous Waste
1998	Law 10/1998	Establishes a common standard for all of the types of wastes. In addition, each type of waste will be covered by specific regulations. In Spain, environmental responsibilities are delegated into autonomous communities.
2005	RD 208/2005	Electrical and electronic equipment and its waste.
2008	RD 106/2008	Transposition of Directive 2006/66/EC. Establishes specific rules for the collection, treatment, recycling and disposal of waste batteries and accumulators.
2010	RD 943/2010	Modified the RD 106/2008 of batteries and accumulators. An update on how to measure the quantity of batteries placed on the market.

to comply with environmental legislation by means of specific waste processing programs.

- Royal Decree 208/2005 of 25 February of electrical and electronic equipment and its waste. Based on the Directive 2002/96/EC modified by the Directive 2003/108/EC. This Decree seeks the prevention of the generation of waste electrical and electronic equipment (WEEE) and, in addition, the reuse, recycling, and other forms of recovery of such wastes to reduce waste disposal. It also establishes an environmentally sound management of all of the electronic equipment put on the market since 2005. Collection rates of at least 4 kg WEEE per inhabitant per year as well as recycling and recovery targets for 10 different categories of WEEE must be fulfilled.
- Royal Decree 106/2008 of 1 February of waste batteries and accumulators. It is a transposition of the Directive 2006/66/EC of the European parliament and of the council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC.
- Royal Decree 943/2010 of 23 of July by amending the Royal Decree 106/2008 of 1 February of waste batteries and accumulators.

The following Table summarises the Spanish legislation regarding spent batteries (Table 2):

In the Spanish context, the relevant legislation on the subject is the Royal Decree 106/2008. The staged implementation of the 2008 Regulations is now complete, and the final obligations came into force on 1 January 2012. The aim of this chapter is to analyse the impact of the emerging environmental regulation on the reverse logistics system for portable batteries in Spain. The following table shows the highlights of this Spanish regulation (Table 3).

The emerging environmental regulation on the reverse logistics system for portable batteries in Spain is a challenge for the current reverse logistics system. In the following section, the current Spanish reverse logistics practices for recovering batteries are described.

Table 3 Highlights of current Spanish regulation regarding spent batteries and accumulators

Highlight	Decree 106/2008
1	Financing schemes should help to achieve a high collection and recycling rate
2	Principle of producer responsibility
3	Producers should finance the collecting, treating and recycling of all of the collected batteries and accumulators minus the profit made by selling the materials recovered
4	Minimum collection rates: 25% by 31 December 2011; 45% by 31 December 2015.
5	Minimum recycling rates: Pb Batteries and accumulators: 65% by 2012; Ni–Cd Batteries and accumulators: 75% by 2012; All of the others: 50% by 2012.
6	Collection and recycling schemes should be optimised to minimise costs and the negative environmental impact of transport
7	Treatment and recycling schemes should use the best available techniques
8	Batteries and accumulators can be collected individually by way of national battery collection schemes or together with waste electrical and electronic equipment by way of national collection schemes established on the basis of Directive 2002/96/EC
9	Autonomous Communities have the responsibility to elaborate waste management plans and to authorise, inspect, monitor, and sanction the activities that are related to waste management.

4 Reverse Logistics Practices for Recovering Portable Batteries: Spanish Case

Currently, the Spanish reverse logistics system for recovering and treatment batteries are changing, due to the European Batteries Directive 2006/66/EC and the corresponding Spanish Law (Spanish Royal Decree 106/2008, 1st February 2008).

The main steps in this reverse supply chain are as follows:

- Selective collection from the consumer
- Transportation to the waste consolidation centre
- Transportation to the recycling facilities
- Sorting the collected batteries
- Recovering valuable components from the sorted fractions and transforming them into secondary material

Figure 3 shows the main actors involved in this reverse logistics system:

There are three types of take-back logistics practices as follows:

- Closed: take back channels for specific companies, e.g., Securitas Direct, a Spanish security company that has its own channel for recovering its alarm batteries (not represented in Fig. 3).
- Open: All citizens can used this channel (represented in Fig. 3).

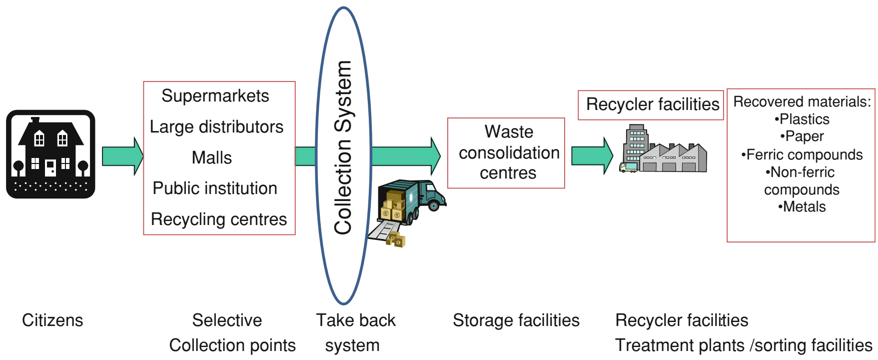


Fig. 3 Logistics system for end-of-life portable batteries in Spain

- Recycling centres: Large containers (60 litres) (one of the selective collection points represented in Fig. 3).

This study focuses on an open system based on selective collection points. In the following sections, a detailed description of the main parts of this reverse logistics system are provided.

5 Selective Collection Points

Selective collection is the point of contact between citizens (generators) and disposal operations. In the Spanish system, this collection point could be located in supermarkets, large distributors, malls, public institutions (e.g., schools, universities, town halls) or at recycling centres (big containers).

According to the European Portable Battery Association (EPBA 2010), it is recommended to have 1 collection point for every 1,000 inhabitants to collect 45% of the batteries by 2015.

To achieve the new legal requirements, Spanish companies have calculated a capacity of 40–45 kg per battery container. They estimate an average of three collections per year (120 kg/bin and year). The specific location of selective collection points is determined by the company in charge of collection. Among the criteria considered to locate those points are the following:

- All points that sell batteries have to allow customers to bring end-of-use batteries.
- High population fluency
- Close to end consumers

Currently, the collection system in Spain is by order. When the container is full, the person in charge calls the collection company to change the container, which takes an average of 4 business days. If there is no request, then at least one collection per year is done.

6 Integrated Management System (IMS)

Spain has a population of just over 47 million inhabitants (Instituto Nacional de Estadística [INE: National Institute of Statistics] 2010) who are distributed in a number of autonomous communities, each of which has environmental responsibilities to comply with environmental legislation by means of specific waste processing programs. Because there are 17 autonomous communities (see Fig. 4) and each needs an Integrated Management System in charge of collecting batteries and transporting them to appropriate storage facilities, these facilities have to be authorised by each region. Therefore, the problem of disposing of the waste is, at best, complicated.

Figure 4 represents (with different colours) the percentage of batteries collected by each autonomous community in 2007. The green colour represents regions with collection rates that are above 25%. The orange colour represents regions with collection rates between 20 and 25%, and, finally, the red colour represents regions with collections rates under 20%.

According to Ecopilas, in 2010, collections totaled approximately 2,300 tonnes of portable batteries and 1,400 tonnes of recycled materials (Ecopilas 2011). Some autonomous communities, such as Navarra, Extremadura, Basque Country, and Asturias, had a collection rate of over 44% in 2010. In Asturias, collections consisted of 5 spent batteries for each 11 units sold in 2010. Whereas some regions are over the 25% set by the law, others are still below 20%. As is shown in Fig. 4, the delegation to the Spanish autonomous communities of environmental responsibilities leads to different situations in each region.

There are four Integrated Management Systems (IMS) authorised in Spain for collecting batteries: Ecopilas (with 70% share of the market); ERP (with a 25% share of the market); ECOLEC with 3% and ECORAEE with 2%. Figure 5 depicts this information.

Ecopilas has been operating in Spain since the year 2000, and this foundation includes the main battery producers (Energiser, Cegasa, Philips, Sony, and Kodak). This IMS collected more than 2 million Kg of spent batteries (corresponding to more than 40 million batteries) in 2010. According to this figure, 29% of the batteries sold in 2010 were collected by this IMS (Ecopilas 2011). There are more than 12,000 bins in the Spanish network, and the cities with more than 1,000 bins are Madrid and Barcelona (Ecopilas 2009). Figure 6 shows the percentage of the different types of batteries collected by Ecopilas in 2010:

The European Recycling Platform (ERP) began operation in 2002. The platform was funded by Braun, Electrolux, HP, and Sony with the intention of developing a European recycling platform. The ERP is a non-profit organisation with the mission of helping companies to achieve the current battery guidelines of European legislation. Duracell is the battery producer associated with this IMS. The ERP has agreements in Spain with retailers, such as Día, Mercadona, Ikea, and MediaMarket, to locate the selective collection points.

The logistics practices for IMS are the following:

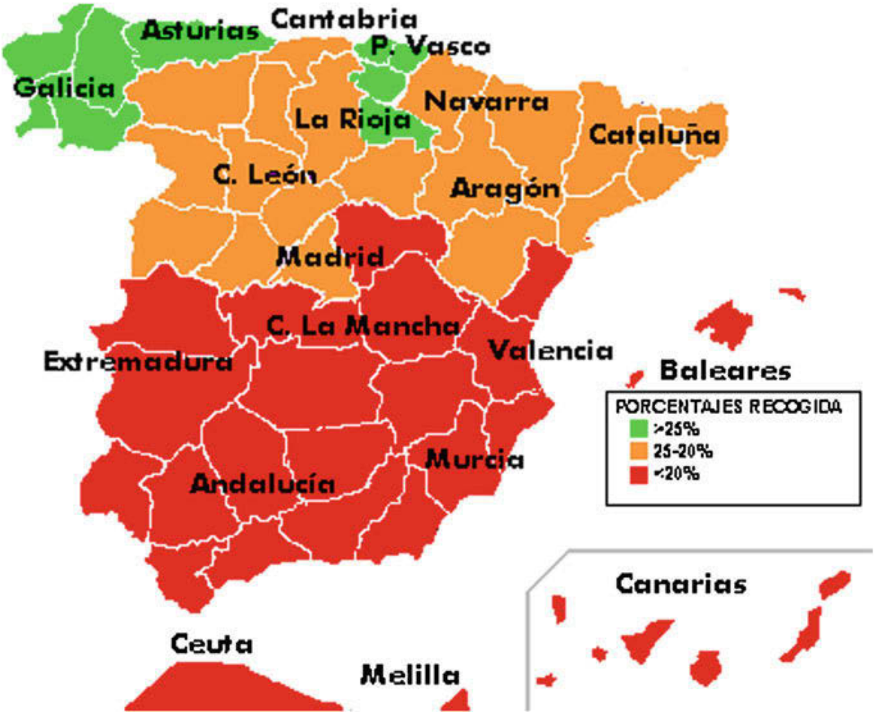
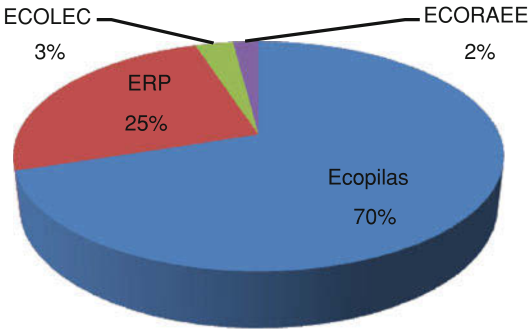


Fig. 4 Percentage of batteries collected by autonomous communities

Fig. 5 Spanish Integrated Management System to collect portable batteries



- Own network: The IMS determines the locations of their own selective collection points. These points are mainly located at large distributors, supermarkets, shopping centres, and outlets.
- Municipal network: recycling centres located by the local municipalities.
- Manager networks: Managers that work with all of the waste types and establish agreements with the different IMSs.

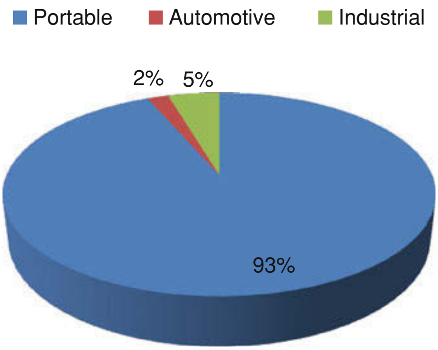


Fig. 6 Types of batteries collected by Ecopilas in 2010 (Ecopilas, 2010)

7 Storage and Load Consolidation Centres

The collection systems are responsible for transporting the spent batteries to intermediary facilities for storage and load consolidation: Waste Load Consolidation Centres (WLCC). There is usually at least one per region (for example, there is one in Andalusia and another one in Madrid). The objective of these storage centres is to lower the cost of transportation to the treatment plant.

8 Recycling Facilities

Once the batteries are collected and stored, they are sent to the treatment plant. Currently, 100% of what is collected is transported to recycling plants, primarily because there are delivery charges (€/tonne) for transporters, which ensure that 100% of the material reaches its destination. The following table shows the main features of the battery recycling plants that are located in Spain (Table 4):

According to our field study, one of the most important recycling facilities in Spain that we have visited is the facility located in Catalonia. This facility has a capacity of 2,000 tonne/year of standard batteries. Through a hydrometallurgical process, this facility obtains plastics, paper, ferric compounds, non-ferric compounds, and, especially, metals with a high purity level (Zinc sulfate: 10.5% Zn, Manganese: 2% in weight and potassium sulfates: 3.6–5% in weight according to Pilagest 2007 data). This facility also has a unit to recycle and to treat button cells. Its capacity is 15 tonne/year, and a distillation process is used to obtain a high purity level of mercury (a minimum purity level of 96% according to Pilagest data).

The performance of the Recypilas facility in the Basque Country is 50 kg of Hg/tonne.

Another facility, such as SOGARISA in Galicia, only performs chemical stabilisation and, after that step, sends the batteries to specific treatment facilities. RECUPYL is another facility located in Spain (Guadalajara) that is only for

Table 4 The main features of the battery treatment plants in Spain

Treatment facilities	Location	Current situation	Types of batteries
VAERSA	Valencia	Out of service	Button cell
RECYPILAS	Basque Country	In service	Button cell
PILAGEST	Catalonia	In service	Standard Button cell
SOGARISA	Galicia	In service	All types
ASER	Basque Country	In service	Standard

Table 5 Batteries treated in Spain in 2007

Treatment facilities	Technological process	Treatment capacity (tonne/year)	Batteries treated in 2007 (tonne/year)
VAERSA	Hg condensation	30	1
RECYPILAS	Hg condensation	8	5
PILAGEST	Hg condensation hydrometallurgical process	15 Button cell 2,000 standard	8 Button cell 593 standard
SOGARISA	Chemical stabilisation	500	215
ASER	Pyrometallurgical process (Waelz oven) hydrometallurgical process	32,000	852
Other Spanish facilities	Storage and security deposits	–	800
Other UE facilities	Sending to other countries (Ni–Cd/ Ni-Mh batteries)	–	50
Total		34,553	2,524

Source: PNIR, 2007

sorting batteries (alkaline and zinc-carbon); it sends batteries to European facilities (located in France and Belgium). The capacity of this plant is 1,600 tonne/year.

According to the Spanish Ministry of Environment, the amount of batteries treated during year 2007 was the following (Table 5):

According to this data, only 7.3% of the Spanish treatment capacity is used. Without a doubt, Spain has enough capacity to treat batteries.

However, only 10.7% in weight of the batteries have been assigned to recycling facilities, and the remaining 7.3% are sent to chemical stabilisation, storage or deposit of security destinations. Therefore, 82% of batteries are stored in inappropriate places, such as private homes, or are removed with other waste in household waste streams.

9 Challenges and Opportunities

In previous sections, the reverse logistics system currently used in Spain for the collection and subsequent treatment of spent portable batteries was presented. The research undertaken to date has allowed us to identify a series of challenges in the system. In the following sections, the main problems identified will be described, and solutions for improvement will be proposed.

9.1 Meeting Regulations

According to data from the Spanish Industry Ministry (MITYC 2011), in 2010, the market for portable batteries (including: button cell, standard batteries, and portable accumulators) in Spain was 13,055,349 kg. According to Ecopilas, in 2010, selective collections amounted to approximately 2,300 tonnes of these residuals, which implies that 18% by weight of the total quantity of batteries and accumulators sold the same year were recycled. Whereas Ecopilas published a collection rate in 2010 of 29% (Ecopilas 2011), a rate greater than the 25% was required by law; according to the official data, the collection index that we have calculated for 2010 was 23.7% (close to the 25% set by the law). This percentage is the result of dividing the quantity collected in 2010 (2,354,219 kg) between the average of portable batteries sold in 2010 (13,141,776 kg), 2009 (12,012,214 kg) and 2008 (4,676,607 kg). These data come from the official register for batteries and accumulators in Spain (published in April 2011 and elaborated by the Spanish Industry Ministry). This record was recently created, and data from 2008 are not reliable. In any case, we can conclude that the collection rate of portable batteries in Spain is currently close to satisfying the 2012 law requirements.

To achieve this collection rate, the Spanish network has installed 12,300 selective collection points, has signed more than 11,000 agreements with distributor companies and more than 20 agreements with local entities and associations (Ecopilas 2011).

The challenge now is to collect, in an efficient way, the maximum number of portable batteries. This goal is needed to achieve a more efficient use of resources, and to achieve the collection targets included in the Directive 2006/66/EC (45% in 2015). In the following sections, we propose solutions to improve this reverse logistics network.

9.2 Need for a Study to Locate Collection Points

The current system of locating collection points was based on placing containers at those points that have requested them. This system has worked and is based on demand. One of the problems with this reverse logistics network is the need for adding more collection points in certain areas, whereas other areas have more points than those recommended. There is a need for locating battery collection containers in an efficient way that justifies a deep study in this area. We propose the development of analytical models to improve the current system used in Spain to locate collection points.

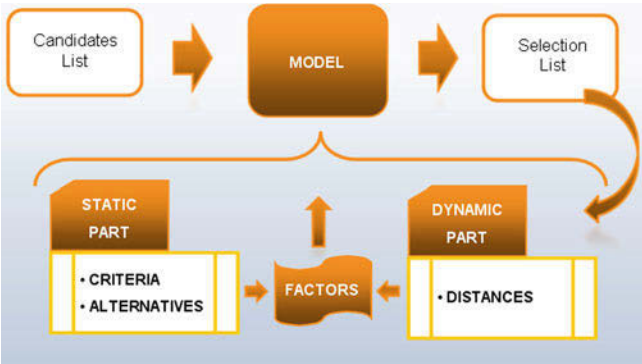


Fig. 7 Structure of the analytical model proposed for collecting batteries (Ponce-Cueto et al. 2011a)

Specifically, we need a model that addresses selecting the most appropriate points for a network of centres with efficient collections, enabling more cost-effective management of resources.

The starting point is a comprehensive set of possible points that are appropriate for installing the collection centres. These items could include supermarkets, schools, municipalities, companies, universities, and recycling centres.

An important aspect is the number of points selected for each specific location. The initial hypothesis is to consider 1 collection point for every 1,000 inhabitants based on studies of EPBA (EPBA 2010).

Another initial aspect to consider is that some points should be included in the network of collection centres by legal imperative. This requirement is the case for the recycling centres: all of the cities with over 50,000 inhabitants should have at least one.

Potential candidates to join the network of collection centres are grouped into eight groups: shopping centres, supermarkets, small shops, universities, public centres, schools, businesses and individuals. The latter could correspond to large communities of neighbourhood partnerships or different types of partnerships.

Our proposal includes two important considerations for selecting the most appropriate points. On the one hand, the characteristics of each specific point can be assessed based on the following criteria: accessibility, public fluency (frequented often), and public awareness. On the other hand, the distances among the selected points are intended to maximise the covered geographic areas to obtain efficient solutions. Figure 7 summarizes the structure of the model proposed.

A detail proposal of this analytical model can be found in Ponce-Cueto et al. (2011a).

9.3 Vehicle Routing and Scheduling Model

Another challenge identified in this study is to develop a vehicle routing and scheduling model for collecting portable batteries. Currently, the model used by managers of this system is a take-back system based on demand. The development of a model for planning these collections could improve the efficiency of the current logistics system.

9.4 Fragmented Logistics System

Environmental competences have been delegated to the autonomous communities; therefore, the current system is fragmented and complex to manage. In addition, different collection rates can be found in each region.

One of the causes of this situation is the fact that authorisation for IMS is granted by the autonomous communities. For an IMS to operate nationwide, they would be obligated to have 17 different authorisations, which, at the very least, from an administrative point of view, would complicate the management of these systems. An analysis of this situation from a logistics point of view results in a requirement for recovery systems that cover a wide geographical area (which would mean operating in different autonomous communities), thus guaranteeing a minimum recovery volume that would, in turn, allow for the application of economies of scale in transport and subsequent treatment.

A possible solution to this problem would be to have a system that coordinates the different administrations (local, regional, and national) and the various agents involved in the system to consolidate sufficient loads to reduce transport costs. Likewise, besides the administrative problem of having or not having authorisation to operate in a specific autonomous community, it is important to mention the necessity of locating the treatment plants in the most appropriate areas to reduce transport costs (regardless of the autonomous community in which it is located or the location that the waste to be treated originated from). Other EU countries, such as The Netherlands, Belgium, and Sweden, have adopted a national collective system (monopoly) to collect WEEE. This model, when properly managed, is considered by many stakeholders to provide the simplest and most effective route to collecting and recycling WEEE, achieving economies of scale (especially in small countries where volumes cannot create a viable market for multiple systems) (Savage et al. 2006). Other actions that may influence the improvement of these systems are the investment priorities or awareness campaigns that may also be different depending on the area. This problem, identified in the Spanish context, not only affects batteries but also electrical and electronic equipment waste, such as mobile phones (Ponce-Cueto et al. 2011b).

10 Conclusions

The objective of this study is to present the current reverse supply chains for collecting, recovering and treating used batteries in the Spanish context. The impact of the emerging environmental regulation of batteries on the Spanish reverse logistics system has been analysed. The characterisation of the current model allows us to identify the main problems and challenges regarding this complex reverse logistics system. Finally, some improvements to the current reverse logistics system are proposed. Specifically, a model that addresses selecting the most appropriate points to set up a network of centres for efficient collection enables more cost-effective management of resources and increases the collection rate.

The challenge now is to collect, in an efficient way, the maximum number of portable batteries. We need to achieve a more efficient use of resources to meet the collection targets that are included in the Directive 2006/66/EC for 2015. Regarding recycling facilities, there are currently a sufficient number of plants (five in total) with sufficient capacity to treat the volume of spent batteries in Spain. Only 7.3% of the Spanish treatment capacity is being used.

The situation of reverse logistics in Spain is interesting because of the delegation of environmental responsibilities to the Spanish autonomous communities. Once the appropriate parameters are determined, it is possible to establish the practices of the communities with greater efficiency. These practices may become a reference for other autonomous communities. Such a benchmarking study would be a natural continuation of the current work, thus providing a path for future research arising from this study.

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Part III
Sustainability Issues: Sector Specific Solutions

Logistic Models to Ensure Residual Agroforestry Biomass as a Sustainable Resource

Borja Velázquez-Martí, Carlos Gracia and Javier Estornell

Abstract Sustainable development strategy promotes activities related to clean energy and energy saving. In this context, actions in forest and agricultural areas which add value to immediate productions and positive externalities are prioritized. The use of agricultural waste is often not viable due to high costs of harvesting and transport operations. In order to consider biomass as an agro forestry sustainable resource to produce biofuels, a high-level system based on the operational concept of the Biofuels Supply Chain sets the basis for a strategic framework which helps to overcome such sustainability. This chapter presents advanced techniques applied by the authors for the detection and quantification of biomass (LiDAR and multispectral images). From these results, logistic models are developed for determining the optimal collection points, managing the best transportation routes and deciding on the desirable location of the processing industries.

Keywords Agricultural residues · Bioenergy · Biomass supply chain · Wastes

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1 Biomass Utilization for Energy

The transport sector is expected to grow more rapidly than any other up to 2020 and it is a crucial sector to the progress of the whole economy. Its energy consumption depends mainly on imported fossil fuels—oil which has led to European regulations in order to reduce its negative contribution to sustainability. These regulations cover a wide range of *measures* such as emission reductions, energy efficiency and promotion of renewable energy sources**.** The aim of this chapter is to show a review of several advanced techniques applied by the authors ranging from biomass detection to route logistics management within the context of biofuels supply chain management.

Under Directive 2009/28/EC on the promotion of renewable energy, Europe established the goal of reaching a minimum 10% share of renewable energy in the transport sector by 2020 in every Member State, whether this is achieved by electricity or hydrogen from renewable energy sources, or 1st or 2nd generation biofuels. This directive also aims to ensure that the use of sustainable biofuels is expanded in the EU, in terms that their use generates a clear and net green house gas (GHG) saving and has no negative impact on biodiversity and land use. Markevičius et al. (2010) pinpointed different key indicators against which to assess biofuels and identifies up to 35 different criteria to estimate biofuels sustainability. These include, inter alia, aspects related to microeconomic sustainability based on cost-efficiency and to planning, pointing out the need of stating clear objectives and writing, implementing and updating a management plan. At the same time, criteria dealing with environmental issues such as ecosystems protection, ecosystem connectivity, crop diversity and soil protection are also held among these sustainability indicators.

The House of Lords report on the EU strategy on biofuels (2006) identifies the major causes for promoting the use of biofuels by EU policies. It highlights the decrease of GHG emissions from transport, the reduction on oil imports dependence and the possible improvement of rural economies. However, the use of biomass does not automatically signify that its production, conversion and use are sustainable.

Biomass is defined as any organic matter not fossilized. Overall, this organic matter has multiple uses, which constitutes the basis of our food and raw material for many industries such as pharmaceuticals, cosmetics, textiles, wood, paper, or some elements of construction. Furthermore, biomass can be a source of energy because it can be transformed into combustible substances called biofuels. It is important to differentiate these two terms because they are confused in many contexts considering them synonymous, when they are not (Callejón-Ferre et al. 2011). Biofuels are end products marketable in the energy market obtained from physical, chemical or microbial biomass, which is its raw material. Undoubtedly numerous sources of biomass types exist. The most relevant sources are listed in Table 1, from Velázquez-Martí (2006). Given the rapid regeneration of biomass in producing systems, it can be considered as a renewable energy source because

Table 1 Classification of the sources of biomass for energy use

Source		Specie
Energy crops: They are cultivated for being transformed in biofuels	Agricultural species	Cardoon, sorghum, miscanthus, sunflower, soybean, corn, wheat, barley, beet, agricultural C4 species….
	Forest species	Poplars, willows, eucalyptus, etc., and C4 species forest…
Remains of agricultural crops	Herbaceous crops	Straw, remains of cereals, vegetable crop residues
	Ligneous crops	Pruning or tree elimination from olive trees, vineyards, etc.
Remains of silvicultural operations		Clear cut, pruning, thining, roads and forest tracks construction, clearing forest for fire prevention, forest disasters (fires)
Wastes from food industries		Skin of fruits (citrus), shells (almond, peanut…), bones (olive) juice pulp industries etc.
Wastes from forest industries		Sawdust and shavings, sanding dust, and trimmings
Wastes from livestock		Manure, animal bedding, dead animals
Marine wastes and products		Seaweed, shells, etc..
Human activities		Food wastes, paper, other industrial wastes

it is inexhaustible. Moreover, waste from the production of biofuels, with emissions in the combustion, presents less pollution than those caused from the manufacture and use of fuels from oil or coal. However, it should be noted that few reports have been focused on biofuels manufactures.

Biofuels derived from biomass processing can be classified into few groups according to the process carried out upon the biomass to obtain it. In Table 2, also taken from Velázquez-Martí (2006), shows the main 9 groups of biofuels pointing their biomass origin, type of transformation that is required, physical condition, and application. As can be observed three of biofuels are solid, three gas and three liquids. Solid biofuels are mainly obtained from wood, but can also be bones, shells and so on. These are mainly used in the combustion boilers for heat or steam production. The heat is absorbed by a carrier fluid, water or oil. The steam is used in a Rankine cycle more or less modified for the electricity production and heat (cogeneration). Liquid and gaseous biofuels can also be used in boilers with the same applications as solids, but they can be used as fuel combustion engines for transport.

The complexity of the biomass challenge and the combined dynamics of the existing agriculture, forestry, energy, waste management and transportation markets set up many impediments on how to configure and model specific individual actions for making biofuels. An appropriate high-level system based on the operational concept of the Biofuels Supply Chain sets the basis for a strategic framework which helps to overcome such difficulties. The biofuels supply chain gives a common structure of the overall system opposed to the organizationally constrained view. It facilitates further systematic decomposition to a more detailed

Table 2 Biofuels classification

Biofuel	Physical state	Source of biomass	Transformation process		Use
Firewood and chips	Solid		Physical	Fragmentation	Direct combustion in boilers Formation of charcoal Formation of pellets and briquettes
Charcoal	Solid	Forest energy crops Ligneous agricultural energy crops	Physical	Fragmentation Carbonization	Direct combustion in boilers Formation of pellets and briquettes
Pellets and briquettes	Solid	Residues of silvicultural operations Residues from forest industries Urban wastes	Physical	Trituration Drying Compaction	Direct combustion in boilers
Bioethanol and biomethanol	Liquid	Sugars from crops such as sugar cane or beet Starch obtained from various plant species among which potato, corn and other cereals or wood	Chemical	Fermentation of sugars Distillation	Directly as fuel for spark ignition engines. As an additive blended with gasoline at a ratio of between 10 and 20 %. In synthesis of high quality biofuels: ETBE, MTBE
Methyl ester and dimetiléster	Liquid	Any vegetable oil, mainly from oil crops: oilseed rape, sunflower and peanut… Waste vegetable oil from frying or industrial processes	Chemical and Physical	Seed press Transesterification of oils with methanol or ethanol, obtaining ester with glycerin	Directly as fuel in combustion-ignition engines (biodiesel)
Pyroligneous oils	Liquid	Wood waste, straw of cereals (rice, wheat..), corn stalks, corn cob	Chemical and Physical	Pyrolysis (biomass flash heating at temperatures between 400 and 450 °C and rapid cooling)	Fuel for boilers to generate heat Fuel for engine Turbines for electricity.
Biogas	Gas	Livestock waste (manure) Sewage sludge, MSW, agricultural residues, industrial organic waste	Chemical	Anaerobic fermentation, resulting mainly methane, nitrogen, ammonia and hydrogen.	Direct combustion in boilers Fuel for motor

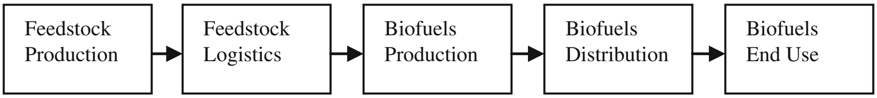


Fig. 1 The biofuels supply chain

level of definition at the same time that allows the application of analytical methods to identify all the flows to and from the conditions associated with biofuel production and use. The biofuels supply chain includes five major elements as shown in Fig. 1. Their main functions can be summarized in the following:

- Feedstock Production produces supplies of biomass including energy crops (sweet sorghum, willow, etc.), agricultural and forest residues (wheat straw, corn stover, sawdust, paper sludge, etc.) and waste materials (manure, fats and greases, etc.).
- Feedstock Logistics implements systems endowed with infrastructure and equipment to accomplish harvesting and collection (baled, bulk, etc.), pre-processing (shredding, pelletizing, briquetting, etc.), transportation (truck, rail, barge, etc.) and storage operations.
- Biofuels Production deploys cost-effective biomass to biofuels conversion meeting quality standards and regulations.
- Biofuels Distribution develops the necessary infrastructure to accomplish biofuels storage, transportation and dispensing operations.
- Biofuels end use

The need for biofuels as substitutes of the petroleum suggests that oilseed and sugary energy crops will suffer a proliferation worldwide. From oilseeds biodiesel will be obtained, from sugary crops will be got bioethanol. The question raised by the promotion of these energy crops is as follows: when the market of biomass for biofuels is widespread and global, will Mediterranean agriculture be competitive in these energy crops if they have the same conditions that the food crops, when they are not being competitive? The referred conditions: small structure of ownership that prevents adequate mechanization, excessive prices of raw material and labour, and adverse weather conditions compared to other parts of the world with more and better distributed rainfall during the year.

Under the sustainable perspective of ecosystems protection and crop diversity, a large amount of biomass can be obtained from Mediterranean agricultural management especially from pruning operations, renewal of plantations and crop residues. Currently these wastes are piled up for burning or shredding, not getting any direct benefit, but rather a cost and also taking high risk of fire danger in the case of fields close to forest areas. The use of this additional biomass as a source of energy allows extra incomes from maintenance operations.

Therefore, pruning is a cultural operation that offers through its wastes a major source of biomass. From this residual biomass it is possible to obtain biofuels, such us chips, pellets or ethanol by means of acid hydrolysis and subsequent fermentation. The use of such wastes is mostly not viable due to high costs of harvesting and transport operations and they end up being burnt. In order to consider the collection of biomass from pruning wastes as an agro forestry sustainable resource, advanced techniques must be applied for the detection and quantification of residual biomass. From these data, logistic models can be developed for determining the optimal collection points, managing the best transportation routes and deciding on the desirable location of the processing industries.

Pruning in fruit trees it is usually performed on an annual or biennial frequency. Among the tasks of pruning can be distinguished traditional and hedge pruning techniques. Hedge pruning is performed by disk machines and consists of flat indiscriminate cuts in the row of fruit-trees. Traditional pruning is done with hand tools and it discriminates the parts to cut from thick branches to small outbreaks. Nowadays, it can be found using either techniques or the concurrence of both so that they complement each other. In the case of hedge pruning, working rates are much higher (about 100 trees per hour and man) than in the manual pruning (2 trees per hour and man) due to the use of high-clipper machine performance (Velázquez-Martí and Fernandez-Gonzalez 2010b). However, the use of hedge pruning machines obviously requires having either large plantations or multipredial concurrence. Once the pruning operations are done, debris on the soil is windrowed to be picked up by scrapers or shredders.

Fruit trees production in Spain is smallholder structured. However, it has led to the creation of associated groups (cooperatives, agrarian transformation societies and marketing companies) which manage larger areas to carry out harvesting operations and selling crops. Therefore, it would be possible that large-scale pruning could also be coordinated from these partnership structures, as the equipment needed to accomplish the pruning and removal of debris, are more expensive and therefore is not sustainable for a small producer.

This chapter presents several advanced techniques applied by the authors ranging from biomass detection to route logistics management within the context of biofuels supply chain management. These techniques allow developing a sustainable framework in which pruning wastes from citrus crops can be converted into sustainable biofuels. In Sect. 2 basic aspects regarding biomass feedstock production such as its quantification and harvesting techniques are described. In Sect. 3 methods and techniques that develop efficient logistic models are presented, such methods are applied by a case of study.

2 Feedstock Production (Biomass)

Large quantity of residual biomass can be obtained from the management of agricultural systems in Mediterranean areas, mainly materials coming from pruning operations, renovations of plantations, and remainders of harvesting. The residual biomass coming from fruit-bearing or herbaceous species is very variable according to species, varieties, planting frame or systems of cultivation. For example, the remainders originated in the vineyards will depend on if they are cultivated in head-training or trellis systems. Moreover, high differences can be found for volume estimation per hectare among varieties; in other ligneous cultivations the total volume will vary according to the purpose of the pruning, species, age of the plantations, size of the trees. Up to now, the biomass produced in Mediterranean agricultural systems have not been mobilised and used for bioenergy production due to technical problems have not yet solved or missing information about quantity and distribution of such biomass. Nevertheless, using this additional biomass as a source of energy could achieve the amortization of the operations management in the frame of a sustainable utilization. The valorisation of woody residues could represent an additional income for the producers apart from the income obtained from the sale of fruit.

2.1 Quantifying Residual Biomass for Logistics Model Implementation

Logistic models for biomass supply start with its quantification. This is usually residual biomass from pruning operations which is distributed on the soil orchards and in order to be incorporated into the supply chain it must be harvested. The amount of available biomass, its location and harvesting costs are the inputs to develop logistic models to get minimum delivery costs and sustainable systems.

The methods for biomass quantification can be focused on levels: First level is to use regression models that have been developed to calculate the pruned biomass from simple measurements, such as sizes of the plant, age, irrigation, and distances between the plants; second level involves determining the biomass of whole plant. Calculating biomass of whole plant allows predicting the available biomass when the plant is removed, and correlating this biomass with agronomic parameters such as fruit production, wastes, nutrients and water and so on.

2.1.1 Regression Models

Several regression models were developed to predict the dry biomass obtained by fruit trees in pruning operations from other variables affecting the available amount. Some of them are reported in Velázquez-Martí et al. 2011a; Velázquez-Martí et al. 2011b; Velázquez-Martí et al. 2011c). In Table 3 the statistics of residual biomass from pruning in the most significant fruit trees in Mediterranean area are shown. The high standard deviation can be explained through the influence of many uncontrolled factors.

2.1.2 Biomass of the Whole Plant

Knowing the biomass of whole plants allows developing more sustainable methods of management. This is due to the relation of plant biomass with agronomic factors such as yield of fruits, residual energetic materials, and industrial

Table 3 Biomass obtained from fruit trees pruning

	Dry biomass (kg tree^{-1})		Dry biomass (t ha-1)	
	Average	Standard deviation	Average	Standard deviation
Oranges	8.52	3.36	4.68	1.75
Mandarins	6.50	4.40	4.34	2.72
Olive trees	22.13	7.61	4.41	3.32
Vineyards (wine) in vase shape	1.25	0.31	2.03	0.50
Vineyards (wine) in trellis	1.29	0.46	2.74	1.07
Vineyards (fresh fruit) in trellis	1.40	0.25	3.18	0.58
Vineyards (fresh fruit) in Y-trellis	3.27	0.45	5.46	0.76
Vineyards (fresh fruit) in horizontal trellis	7.04	0.97	7.82	1.08
Almond	8.42	4.85	1.05	0.60
Peach	7.92	3.81	3.73	1.65

products obtained from pruning and felling. For this, it has been necessary to develop methods of measurement that allow an effective quantification in extensive zones. Dendrometry and dasometry have been used widely in forest studies to estimate the timber volume. However, few researches have been conducted in fruit trees due to the difficulty associated to their crown structure. The total biomass will depend on: the agronomic characteristics of the plantation, species, height of the plant, diameter of crown, diameter of stem, type of pruning, age, distance between plants, non irrigated land or irrigated land, etc.

Regression models can be used to define the volume of the plant from the crown diameter (D), stem diameter and plant height (H). Obtaining the volume of the structures, the existing biomass will be determined by means of the application of the density.

Other method to determine the soild volume of all the existing branches in each crown and stem of the plant is applying the Occupation Factor. This is the relation between the apparent volume of the crown and the real volume of the branches, expressed by the Eq. 1:

$$OF = \frac{\text{Volumen real of the crown}}{\text{Apparent volumen the crown}} \tag{1}$$

2.1.3 Multispectral Images

Remote sensing is a science aimed at obtaining information from the Earth's surface from images acquired without being in contact with it, relying on measurements of electromagnetic energy reflected or emitted by its surface. A fraction of the solar radiation is reflected by the earth surface, and other fraction is transmitted in depth, and finally is absorbed by the materials being transformed into heat. The proportion of incoming radiation that is reflected, absorbed and transmitted depends on the characteristics of the surface. Variations of reflectivity electromagnetic spectrum allow to discriminate different types of structures and to relate with physiographic features. The remote sensing data have allowed to estimate a wide range of biophysical variables, such as the classification and inventories of forests and to define the quantitative estimation of stand parameters such as volume and biomass, index leaf and humidity.

The spectral bands more used in remote sensing are:

- Visible spectrum (0.4–0.7 μm): three elementary bands are distinguished, blue (0.4–0.5 μm), green (0.5–0.6 μm) and red (0.6–0.7 μm)
- Near infrared (0.7–1.3 μm), mid-infrared (1.3–8 μm, far infrared or thermal (8–14 μm)
- Microwave (from 1 mm).

Analysis of the spectral behavior of surfaces in different portions of the electromagnetic spectrum (bands) allows determining some synthetic indexes or variables associated with biophysical processes, such as biomass production. These can be obtained by means of algebraic operations with bands corresponding to different portions of the electromagnetic spectrum (Fensholt et al. 2004). Some of these indices and variables include the *Normalized Difference Vegetation Index* (NDVI), *Enhanced Vegetation Index* (EVI) and *Photochemical Reflectance Index* (PRI), *Modified Soil-adjusted Vegetation Index (MSAVI).* All these indexes can be linked directly with the surface biophysical attributes (e.g. amount of biomass present in a given structure).

It has been demonstrated that the NDVI has a strong relation with biomass (Ripple 1985). The estimation of biomass is obtained through regression models between the NDVI value computed for every pixel and its biomass value. For this, field sampling of biomass may be completed by means of dendrometric methods and they may be compared with the NDVI values obtained for every pixel. On the other hand, NDVI is also related with:

- *Leaf area index* (LAI), which is the leaf area per m^2 (Asrar et al. 1984);
- *Aboveground net primary productivity* (ANPP), which des biomass generated per m^2 and year (g/m^2 years) (Paruelo et al. 2004).
- Fraction of radiation photosynthetically active absorbed by green tissues (fRFAA) (Myneni et al. 1995).

The NDVI have some problems related with saturation at high levels of biomass and its sensitivity to the substrate below the canopy

The *EVI* is similar to *NDVI* but incorporates other spectral bands to “optimize” the signal from vegetation, particularly at high levels of biomass. Qi et al. (1994) defined *Modified Soil-adjusted Vegetation Index* that allows to improve the results produced by NDVI index in areas with a high degree of exposed soil surface.

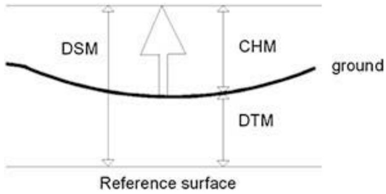


Fig. 2 Representation of a DMS, a DTM, and a CHM

2.1.4 Biomass Quantifying by LiDAR Data

Numerous new management tools are based on LIDAR data which have been used successfully in forest applications (Reutebuch et al. 2005). Airborne Light Detection and Ranging (LIDAR) is an active system of remote sensing which allow measuring extremely large amounts of information in 2 and 3 dimensions of the terrestrial surface in the case of the airborne LIDAR or the objects above the ground for the terrestrial LIDAR such as trees. It works by measuring the time delay from when a pulse is emitted by an airborne or terrestrial sensor to when it bounces back from the terrestrial surface. LIDAR systems can register the return signal of an emitted pulse in different echoes, and can be used in conjunction with a differential GPS and an inertial system to calculate the coordinates of the point where the reflection takes place. This information can then be used to determine ground elevations, the elevation of objects above terrestrial surface level, and the height of forest canopy. The three categories of information obtained are known as Digital Terrain Model (DTM), Digital Surface Model (DSM), and Canopy Height Model (CHM), respectively (Fig. 2). In addition, LiDAR systems provide intensity records for each laser return. Intensity values are defined as the ratio of the power returned to that of the power emitted, and are influenced mainly by the reflectance of the reflecting object. These data could be used to classify tree species and to estimate structural and biophysical characteristics of forest stands (García et al. 2010).

Elevation data provided by a LiDAR system have been widely applied in different fields: river flood modelling (Cobby et al. 2001); changes in beach sand (Shrestha et al. 2005); building extraction (Hermosilla et al. 2011), and above all in forestry applications (Popescu 2007). For applying this technology is necessary to carry out a previous characterization of this vegetation in different areas calculating parameters or indicators derived from field data. Without this characterization, the parameters extracted from LIDAR data cannot be correlated with the vegetation field data and this work would be slower and require more effort (Velázquez-Martí et al. 2010).

Previous researches have demonstrated the ability of LiDAR data to predict variables that characterize structure forests (García et al. 2010). Some studies revealed a high correlation between LiDAR data and biomass in old growth forests (Nelson et al. 2004). For predicting forestry variables, two methodologies can be developed (Hyyppä et al. 2008): estimation of dasymetric variables calculating regression models between field data and statistics derived from LiDAR data in plots-stands (Pascual et al. 2008); and studies focused on the estimation of dendrometric variables being necessary a previous delineation of the tree crown (Forzieri et al. 2009). To estimate the dasymetric variables such as height, biomass, and volume, statistics derived from LiDAR data are used as explanatory variables in the regression models. Firstly, the bare-earth surface elevation is subtracted from each LiDAR data by using a DTM calculated. Then, for each plot the following statistics (LiDAR height metrics) can be obtained: maximum height, mean, standard deviation, coefficient of variation, kurtosis, skewness, interquartile distance, percentile values (5, 10, 20, 25, 30, 40, 50, 60, 70, 75, 80, 90, 95th percentiles). Some studies have reported that the mean height of the CHM shows a good correlation with the canopy height (Naesset 1997). For biomass, both mean height and the coefficient of variation show a high correlation with biomass (Donoghue et al. 2007).

To compute DTM from LIDAR data it is necessary to apply algorithms to eliminate points belonging to any object above the ground surface such as vegetation or buildings. A comparison and classification of methods can be found in (Sithole and Vosselman 2004; Meng et al. 2010). DTM accuracy depends on several factors: both vertical and horizontal errors related to the system (GPS, INS, laser scanner); methodology and algorithms; complexity of the target; and data characteristics (Hyyppä et al. 2008). Data characteristics such as flight height, point density, number of echoes, and scan angle are related to the accuracy of a DTM. The greater the flight height and scan angle, the greater the error (Ahokas et al. 2003). Point density and distribution of the points also play an important role in the accuracy of a DTM (Baltsavias 1999). Another factor related to the data characteristics affecting the accuracy of a DTM is the scan angle. In dense vegetation areas, a relationship between the pulses reaching the ground and the scan angle has been found. The likelihood of obtaining laser pulse returns from the ground can increase with narrow scan angles (Hopkinson et al. 2005). Finally, factors such as the presence of dense vegetation and high slopes that characterize the complexity of the target produced a decrease in the accuracy of a DTM (Hollaus et al. 2006).

Sithole and Vosselman (2004) reported that all algorithms produce an accurate DTM in flat areas without vegetation. In contrast, larger errors can be obtained in urban and vegetation areas with steppe slopes. The accuracy can vary from 0.10 to 0.15 m in flat areas without vegetation to around 0.30–0.40 m in areas densely covered by vegetation (Estornell et al. 2010). In studies of low vegetation (shrub or low trees), the accuracy of the DTM can be a significant factor to be considered because the low differences in height between the vegetation and ground makes more difficult to separate from all LiDAR data, those belonging to the ground. Errors in the filtering processing can produce an underestimation or overestimation of vegetation height. Meng et al. (2010) reported that low vegetation is often ignored by ground filters. Therefore, before predicting low vegetation parameters, it would be necessary to assess the accuracy of a DTM calculated in areas occupied by low vegetation with high slopes (Estornell et al. 2010). In contrast, the accuracy of a DTM is less relevant in tree analysis as the differences in height between the ground and the trees are larger and LiDAR data associated to the ground or undergrowth are often removed.

In addition to the DTM, LiDAR data allow to obtain DSM. An DSM is a geometric description of the terrestrial surface and objects located on it such as trees and buildings (Priestnall et al. 2000). Unlike the DTM, the DSM is calculated from the selection of the highest elevation points in a neighborhood of fixed size. For computing a DSM is often selected the first pulse registered by a LiDAR system. In contrast, for computing a DTM the last pulse is often used. From a DSM and a DTM a CHM can be obtained as the difference between both surfaces (DSM-DTM). The CHM is the reference surface to derive statistics that will be used to estimate dasymetric variables. The CHM is also the reference surface to obtain characteristics of individual trees applying image segmentation processes (Hyyppä et al. 2001). Not all vegetation studies from LiDAR data use a CHM to estimate forest variables. In other studies (Estornell et al. 2011), statistics derived from all LiDAR point cloud are obtained to be used as explanatory variables in the regression models. For this, previously the bare-earth surface elevation is first subtracted from each LiDAR point by using the DTM.

In forest applications, it was reported that when the LiDAR and spectral data are all used together the prediction models improved significantly. In some studies, statistics derived from the distribution of intensity values by plots are also calculated obtaining better results in the prediction of volume and biomass (García et al. 2010).

Apart from the methodologies above reported, Velázquez-Martí et al. (2010) developed a dendrometric methodology to calculate biomass volumes in shrub stands from simple measurements such as stand area and dominant height of vegetation (measurements that could be derived from LiDAR data). For this, it was applied the Occupation Factor (OF) defined by the relation between the sum of the real volume of each plant within a stand and the apparent volume of the stand (materials and holes) defined by a solid of revolution. The apparent volume can be obtained multiplying the area that occupies the vegetation by the vegetation height derived from the CHM. Applying the OF and the dry density, the real volume of vegetation can be calculated; from this value and material density, the biomass can be estimated.

Little research has been conducted in fruit trees. The methodology reported in this section could be applied for this vegetation to estimate its biomass, which is a relevant variable to evaluate landscape and ecosystems (Zheng et al. 2004), to estimate CO_2 sinks and cellulosic material as a potential source of renewable energy (Popescu 2007).

2.2 Methods for Biomass Harvesting

Harvesting costs are a key in the biomass delivery chain. These costs can be a 30 % of the total in biofuels. The main harvesting methods depend on the technology used. A classification is shown in Velázquez-Martí and Fernández-González (2009b):

- *Harvesting with transportable chippers*. These chippers are machines generally pulled by tractors or mounted on a truck. They work in the road next to the field because they cannot be driven into the orchard or forest plot. Therefore they require a previous concentration of materials to carry out the splintered in fixed position. This previous concentration should be carried out manually, by means of a forwarder, and tractor with a rake. The chipper places the materials in the feed platform by means of a crane. After the grinding, these machines have a continuous system of discharge, chips being placed directly in a container by a pneumatic impulsion in order to transport. The containers are transported to the energy industries by means of trucks. Due to the tractor that concentrates the residues will do different piles separated a variable distance among 60–80 m; the chipper will be obliged to go short distances during the time of work.
- *Mobile Chippers*. These chippers can go among the lines of cultivation. They can be manually loaded by operators, by mechanical crane, and by pick up header directly on the stand. Chipper with manual feeding consists of a hopper where several operators insert the materials while the machine is pulled by an agricultural tractor with very slow velocities. Chippers with pick up header are machines with an axle that raises material, and other more above inserts this into a splinter chamber (Velázquez-Martí and Fernandez-Gonzalez 2009a).
- *Bundling machines* are autonomous equipments for collecting forest or agricultural ligneous remains and use compaction of the materials as work principle. The feed system is carried out by an adapted crane that places the materials in the compression device. After increasing the density, the materials are tied by means of a plastic cord forming either cylindrical or prismatic bundles (Velázquez-Martí 2006). The bundles are placed in piles by means of the crane which will be transported in conventional truck. When the transported materials arrive at the facility they keep being stored until their use in the energy production process. Bundles should previously be splintered in static chippers installed in the transformation industries.

The described variants were evaluated in plantations from Mediterranean areas. Times of work taken in the organizational options bear a linear relationship with the amount of biomass of a plot. As a guide, we report the equations in Table 4, where T is expressed in hours of total work per hectare and B is the biomass present in the plot in t/ha. Notice, there is a high dispersion due to the number of factors that can influence in this work time, such as track width, space for turning the machine, type of crop, etc.

3 Feedstock Logistics

As defined above, feedstock logistics accomplishes harvesting, pre-processing, collection, transportation and storage operations. The sustainability of this element of the biomass supply chain can be asserted by solving its associated location and

Table 4 Estimated work time for chipper in collection of residual biomass from pruning (Velázquez-Martí and Fernández-González 2009b)

Harvesting system	Equation
Mobile chipper with manual feeding, residues being previously aligned in the track between crop lines	$T = 1.15 \cdot B + 0.53 \quad R^2 = 0.68$
Mobile chipper with mechanical crane, residues being previously aligned in the track between crop lines	$T = 0.81 \cdot B + 0.64 \quad R^2 = 0.64$
Mobile chipper with pick up header, residues being previously aligned in the track between crop lines	$T = 0.21 \cdot B + 0.68 \quad R^2 = 0.71$
Transportable chipper, residues being previously concentrated in a border of the orchard	$T = 0.15 \cdot B + 0.59 \quad R^2 = 0.77$

routing problems. This will mean both the definition of the storage locations and vehicle routing planning. Store locations are concentration nodes where biomass has to be concentrated following minimum cost criteria. Vehicle routing planning is accomplished in terms of minimizing travelled distances which entails equivalent reduction of fuel consumption and of working time.

Models based on algorithmic approaches to bound biomass concentration locations in a region are reported by authors in (Velázquez-Martí and Annevelink 2009; Velázquez-Martí and Fernández-González 2010a). These locations cover a wide area of production and are considered as source nodes for conversion facilities (power plants) inside the supply chain. The followed criteria for selection of source areas are: firstly, a minimum production of available biomass type; and secondly, minimum harvesting and collection costs. An explanation and an illustrative example on the specific application procedure it is described in Sect. 3.1.

The database for these models is composed of spatial surveys on forest and agricultural biomass given in GIS maps (shape files). The area associated to each concentration point is usually divided into 1 × 1 km subareas so that land use and diversity are ensured sufficiently over the territory. Harvesting and collection vehicle routes will have to be defined for each one of these subareas. This routing problem and a solution approach based on genetic algorithms are described in Sect. 3.2.

3.1 Algorithms to Locate Concentration Points for Biomass Supply

Many logistic models have been developed to determine the best alternative for supplying bio-energy systems, including the Bioloco Model (Biomass Logistics Computer Optimization) developed by Annevelink and de Mol (2007) and Borvemar model (Velázquez-Martí and Annevelink 2009). By means of purpose-built computer models, either one specific objective can be optimized by linear programming or several heterogeneous objectives can be combined by applying goal programming: maximize profits, minimize costs, minimize greenhouse gas emissions, maximize energy returns, minimize energy use, and maximize energy profit. Bioloco is an optimization model that uses integer linear programming. The input is a network structure in which all relevant parameters should be included. These parameters are cost data (e.g. transport costs per km, pre-treatment costs and energy conversion costs), capacity constraints, storage losses, and seasonal supply/demand variations. A file with all the input data needed for optimization is generated from a spatial database. Bioloco is therefore a system for analyzing biomass network models. The network model is built up from nodes with one or more depots, with arcs connecting the depots. Each depot is a source of a certain biomass type, or a storage point for a certain type or production facility (e.g. power plant) where biomass is used. Arcs represent connections between depots, containing information regarding to pre-treatment for loading and/or unloading, taking seasonal fluctuations in supply/demand and moisture losses and dry-matter losses. The flows in the network are regulated by the biomass required by production facilities and the supply capacity from the biomass sources. To be able to combine GIS spatial studies with linear programming models it is necessary to build a network from a digital map (Velázquez-Martí and Annevelink 2009). The Borvemar model is a mathematical calculation method to select the actual points on the map at which biomass can be collected and which can subsequently be considered as biomass sources in a network model (Velázquez-Martí and Annevelink 2009; Velázquez-Martí and Fernandez-Gonzalez 2010a). The algorithm provides the location of points where biomass can be concentrated with a minimum amount of available biomass and a limited area. These biomass source points should be connected with the other possible consumption points (e.g. power plants). Using these concepts, a network structure can be built. Optimization of the selection of the source points to supply the power plants can therefore be solved by linear programming of the structured network from a digital map.

The input data to mapping the spatial distribution of available biomass requires quantification studies for all crops. Time and cost of technology for collecting the biomass are also necessary for planning the logistics. The origin of the process consists of calculating the available amount of biomass from equations studied. Then the harvesting cost is calculated. Finally, biomass spatial distribution allows selecting the points of concentration for storage/supply from decision models. In this phase of the process, Geographic Information Systems (GIS) can be used to integrate several sources of geographic data, such as official cartography (Land Registre), satellite images and LiDAR data.

The steps for every iteration for applaying *Borvemar* model are dercribed (Velázquez-Martí and Annevelink 2009).

Step 1. Every quadrant *aij* is checked to find those that have a specific type of available biomass greater that Q located inside a radius R (e.g. $R = 2$ km).

$\mathrm{D}(a_{ij}, a_{mn}) < \mathrm{R}$

$\sum_{i,j}^{n,m} m(a_{ij}, a_{nm}) > \mathrm{Q}$ 60 t of biomass (selected types) per year

Step 2. The quadrants, which have the previous conditions, are selected.

Step 3. For every quadrant a_{ij} selected, the cost to harvest and collect all available biomass from all other a_{mn} *to* a_{ij} is calculated such as $D(a_{ij}, a_{mn}) < R$. The cost is obtained by the equation

$$C_{ij} = \frac{\sum_{ij}^{nm}\left[m(a_{ij}, a_{nm}) \cdot \vec{H} \cdot \vec{r}_{nmb}\right] + \sum_{ij}^{nm} \frac{m(a_{ij},a_{nm})}{CT} \cdot CF_i + \sum_{ij}^{nm} \frac{D(a_{ij},a_{nm}) \cdot m(a_{ij},a_{nm})}{CT} \cdot CV}{\sum_{ij}^{nm} m(a_{ij}, a_{nm})}$$

CFi is the fix cost of the transportation (€/travel). It includes the operator cost during the load time (3–4 h); *CV* is the variable cost of the transportation (€/km). It includes fuel consumption and operator. *CT* is the transport capacity (e.g. 5 t/travel). The parameter r_{ija} is the ratio of biomass type *a* inside quadrant a_{ij}; the parameter r_{ijb} is the ratio of biomass type *b* inside quadrant a_{ij}. Also, a harvesting or collecting cost vector $\vec{H} = (H_a, H_b, \ldots, H_z)$ is defined. The parameter H_a is the cost of harvesting type *a* biomass; the parameter H_b is the cost of harvesting type *b*. The product $\vec{H} \cdot \vec{r}_{ij}$ is the harvesting cost for all biomass in the quadrant a_{ij}. $(\vec{H} \cdot \vec{r}_{ij} = H_a \cdot r_{ija} + H_b r_{ijb} + \ldots + H_z r_{ijz})$

Step 4. All the elements a_{ij} are ordered according to the cost. The a_{ij} with the smallest cost is selected.

The **first sub-area A1** is formed with all a_{mn} such as $D(a_{ij}, a_{mn}) < R$ and *Cij* minimum

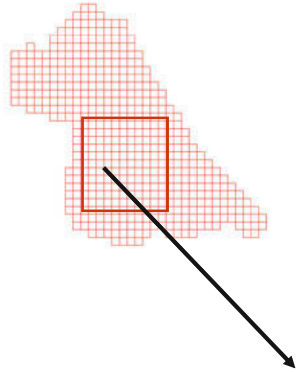
In the Fig. 3 the first iteration of borvemor model is applied to La Safor (Valencia) for a pixel size of 1 × 1 km. From Fig. 3 amount of biomass that is available within 2 km radius of every a_{ij} is calculated. The harvesting and concentration cost is also calculated in Euros/t. And the point with lowest cost and more biomass than 60 t/year in a radius of 2 km is selected.

The input for applying the second iteration is the quadrant shown in Fig. 3 but with the area 1 removed. Then, the steps 1–4 are repeated. After six iterations more subareas with the conditions “minimum biomass 60 t in a 2 km radius” do not exist, therefore the calculation process is finished. In Fig. 4 the selected subareas for the initial grid are shown. Figure 5 depicts the selected points in the La Safor region for a minimum biomass of 60 t/year in a radius of 2 km.

3.2 Algorithms to Accomplish Optimum Vehicle Routing Sequences

The biomass harvesting and collection problem (BHCP) appears when minimum cost routes for chippers, trucks, tipper trailers and tractors have to be defined by describing the sequence in which biomass has to be harvested and collected from different production locations (orchards) and transported to the common storage

Iteration 1



Step 1. Every quadrant a_{ij} is checked to find those that have a specific type of available biomass greater that Q located inside a radius R (e.g. $R = 2$ km).

$$D(a_{ij}, a_{mn}) < R$$

$$\sum_{i,j}^{n,m} m(a_{ij}, a_{nm}) > Q_T \quad 60 \text{ t of biomass}$$

5.02	4.63	7.00	4.41	5.36	5.48	6.38	8.87	4.35	4.97
6.17	7.01	7.11	8.55	7.00	6.87	3.28	4.84	4.66	8.71
7.37	4.17	8.39	3.41	8.45	3.68	4.71	5.93	8.92	3.84
6.76	7.90	4.28	6.21	3.05	8.69	7.44	5.57	8.22	8.21
3.54	6.80	4.83	7.61	8.21	8.49	8.34	6.56	6.68	7.26
6.98	5.38	6.73	5.10	6.49	8.67	4.20	5.28	8.61	3.83
6.66	6.26	5.83	6.71	6.11	7.47	7.16	4.82	3.93	3.37
4.42	3.23	3.16	5.90	8.22	4.18	8.74	6.15	5.12	4.63
5.36	8.60	7.96	3.57	7.27	3.95	6.03	3.35	8.47	8.28
3.39	8.38	8.61	5.13	8.12	3.24	4.16	8.09	5.67	5.31

Fig. 3 Quadrant selection of La Safor where the value is the available amount of biomass per year in tones

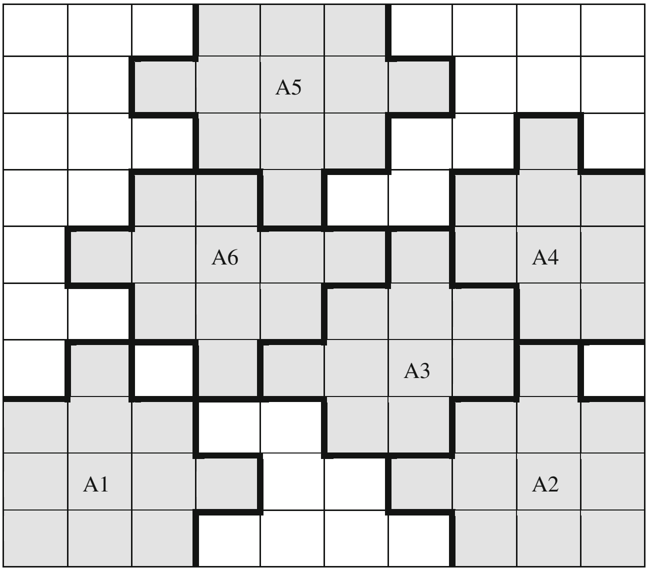


Fig. 4 Selected sub-areas after 6 iterations of the Borvemar model

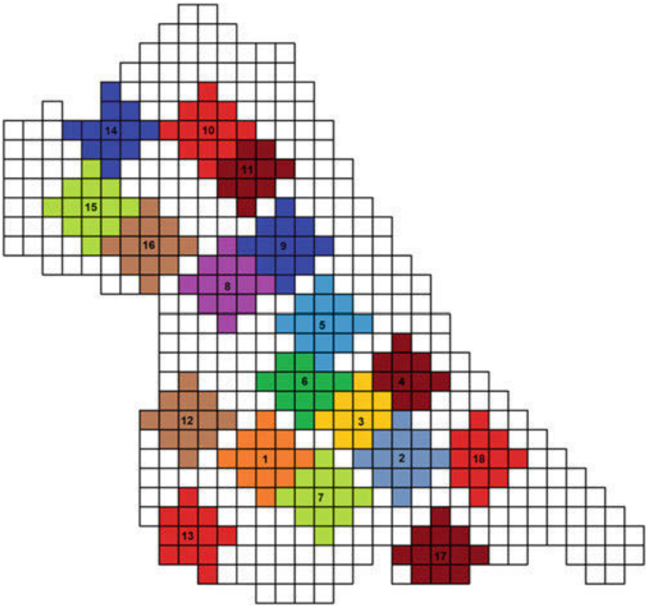


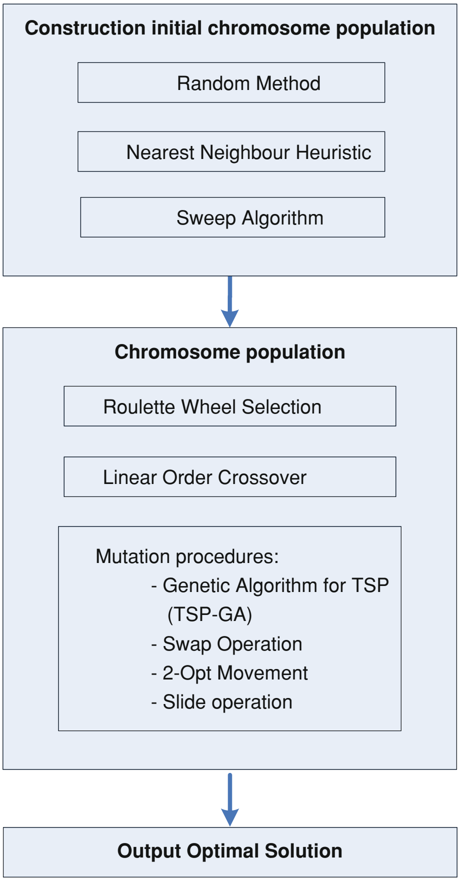
Fig. 5 Subareas and its collection points from Borvemar model in "La Safor" county (Valencia, Spain) when Q = 60 t/year and R = 2 km with 18 iterations

location (biomass concentration node) for further distribution to a conversion facility. As pointed out in Sect. 2.2, biomass harvesting operations involve several collaborative machines: a chipper and its propelled machine (either a tractor or a truck), a tractor with a rake and a tipper trailer to transport biomass. These machines working together will require an accurate planning of their routes and sequences in order to develop their tasks efficiently.

The BHCP belongs to a class of Operations Research problems known as vehicle routing problems (VRP). The VRP has been extensively discussed and has provided for over 50 years optimal solutions to fleet planning in many real applications involving planning of vehicle fleets. Routing Problems can be modelled in terms of mathematical programming. According to the theory of computational complexity, most of them are of the NP-Complete (Garey ad Johnson 1979). Therefore, procedures proposed usually focus on the use of algorithmic methods based on the application of meta-heuristics. These techniques have become recognized as one of the best approaches to solve many real complex combinatorial problems.

Authors have developed a hybrid approach based on genetic algorithms (HGA) and local search methods to efficiently solve the BHCP in order to ensure maximum operational efficiency to convert biomass into an agro forestry sustainable resource to produce biofuels. A general overview is depicted in Fig. 6. Numerous practices based on hybrid approaches produce more successful results than either of their pure methods applied separately (Chen et al. 2008), always relying on the

Fig. 6 Structure of the HGA approach



synergy of both methods to provide search guidance while balancing solution exploration and exploitation. Previous hybrid approaches applied successfully to solve routing problems are found in (Wang and Lu 2010)

The main features of the approach can be summarized in the following:

Genetic encoding. A solution is defined as a pair of vectors. The first vector (sequence vector) contains a permutation of n elements that represents the ordered sequence that will reflect all different biomass collection points (B). The second vector (breakpoints vector) contains the position of V-1 elements from the above sequence vector delimiting the different routes.

Initial population generation method. The production of initial individuals proposed results form a random creation method in combination with the nearest neighbour constructive heuristic.

Fitness value. The total distance travelled will be the fitness value used. The shorter the distance, the more efficient the solution is.

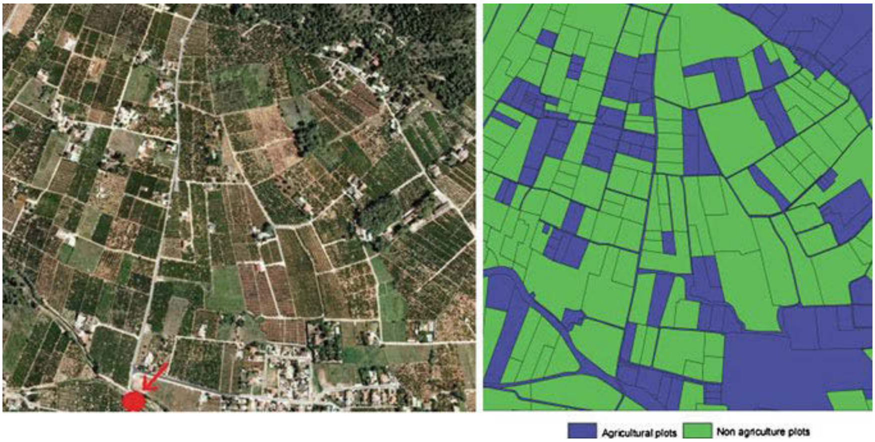


Fig. 7 Area of study's orthophoto

Genetic operations. Linear order crossover operator (Davis 1985) and classical mutation procedures Martin et al. (1991) are employed to accomplish genetic operations.

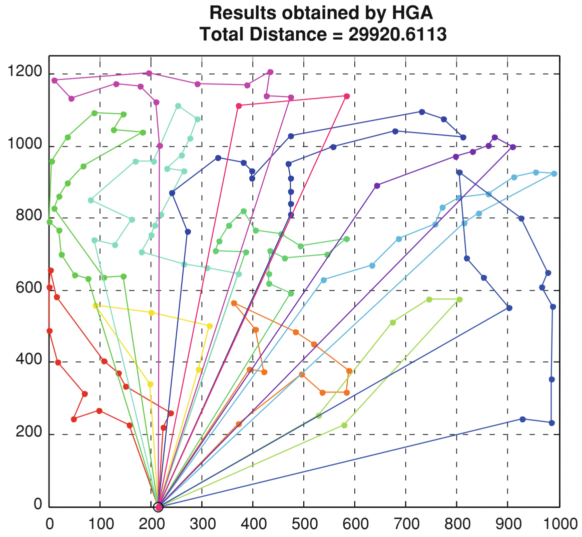
As a case of study, the proposed HGA is applied to a 1.2 × 1 km surface of land located in province of Valencia (Spain). Once applied Borvemar model (Fig. 5) to La Safor County, Valencia, 18 biomass storage locations are obtained, each of which comprising several 1 × 1 km grids. Figure 7 shows the 1.2 × 1 km grid case of study. Notice that it has been highlighted in a red circle the entrance location to t-he grid, so that all vehicles must go through that point in order to arrive to the storage node.

The division of such surface in plots is available from the Agricultural Plots Geographic Information System (SIGPAC) from Spanish Ministry of Agriculture. Figure 8b differentiates the intended use of each plot according to the Land Registry. Agricultural use (citrus) plots are coloured in blue and plots for other uses (roads, forest,…) are coloured in green.

From all these information we are able to obtain data needed to define the problem instance and apply the HGA. That is: road curvature among plots, residual biomass production estimated and its centroid for each plot. Specifically 146 agricultural plots are contained in this 1 × 1 km surface. Their average area is 0.438 ha ranging from 400 m^2 to 2.5 ha. The loading capacity has been set to 24 t of biomass.

Figure 8 illustrates the solution obtained for this instance with the approach. Each point represents the centroid of each agricultural plot. Each route is identified by a different colour; notice that all routes have their starting and ending point at the same location identified above.

Fig. 8 HGA performance



4 Conclusions

This chapter presents a review of several advanced techniques applied by the authors ranging from biomass detection to route logistics management within the context of biofuels supply chain management. These techniques allow developing a sustainable framework in which pruning wastes from fruit trees crops can be converted into sustainable biofuels. The purpose of this chapter has been clarifying the steps to follow criteria that optimize the logistic resources. These steps are:

(a) Applying techniques for quantifying the biomass in the orchards at two levels; field level from dendrometry methods and large areas level from remote sensing tools, base on multispectral images and LiDAR,
(b) Selection of the best harvesting method, knowing the resources used for each option,
(c) Determining the location of points where biomass can be concentrated with a minimum amount of available biomass and a limited area. These points can subsequently be considered as biomass sources in a network model,
(d) After selecting the areas for harvesting biomass, a genetic algorithm is applied to minimize rural collection machines from cadastre data.

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Energetic Assessment of the Broiler Poultry Supply Chain

Jesús Muñuzuri, Rafael Grosso, Pablo Cortés and José Guadix

Abstract In the food supply chain, energy efficiency can be seen as a combination of technological and organizational efficiency, in all the stages of the food system. We describe the process to monitor and manage energy consumption in the supply chain, which consists of four steps: initial assessment, process design, and evaluation and application opportunities. We then apply the methodology to a broiler poultry manufacturer and distributor located in the South of Spain. Once the energy consumptions have been quantified and structured, we apply a comparative analysis to highlight those processes that represent the largest energy costs. We propose several actions for improvement (related to warehousing, inventory management, transportation, reverse logistics, energetic management, etc.), and evaluate the energetic situation of the company ex-ante and ex-post, using the appropriate indicators, in order to determine the degree of energy efficiency of the company.

Keywords Broiler poultry · Energy assessment · Logistics

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1 Introduction: The Broiler Poultry Supply Chain

Chicken production takes place on a large scale, and EU countries are consuming increasing quantities of cut-up and/or frozen chicken instead of whole chickens. According to the MTD Guide (2006), in the year 2000 the total number of broiler chickens in the world came to approximately 20 billion; of these, nearly a fourth were produced in the United States, 14% in the EU and nearly 19% in China. Chicken production in the EU exceeds 4.4 billion per year, and the EU country with the highest rate of chicken consumption is Portugal, followed by the UK, Denmark, Spain, France and the Netherlands. France is the largest producer of poultry meat in the EU, followed by the UK, Italy, Spain, Germany and the Netherlands.

Spain is one of the most important poultry-producing countries in the EU; in fact, it ranks third behind France and the UK (MTD Guide 2006). However, its international market is very limited. Of Spain's total poultry production, 80% corresponds to chicken. Approximately 600 million chickens are slaughtered annually. With regard to other types of broiler poultry, (duck, goose, etc.), Spain ranks 12th amongst EU countries.

Spain's three most important poultry-producing autonomous communities are Catalonia, Galicia and Castile-Leon in that order. Counting chicken only, Galicia is ranked first (36%), followed by Catalonia (21%) and the Basque Country (13%). The autonomous communities in which the most chicken is consumed are Valencia and the Balearic Islands. Broiler chicken consumption comes to about 21 kg per capita, which is one of the highest averages in the EU.

The chicken market contains three large segments: fresh, frozen and cooked chicken. Fresh chicken accounts for 66% of retail sales, frozen makes up 26%, and cooked chicken, 8%. In turn, poultry meat makes up 20% of household food consumption. The most commonly purchased product is whole chicken, followed by chicken breasts, and then drumsticks.

The recent tendency in the chicken supply chain is to create added-value chicken products and prepared meals, which are also sold frozen. The popularity of frozen chicken products grew with the introduction of new household technologies (freezers, microwaves, etc.). Frozen and refrigerated products are being increasingly sold under retailers' brand names.

The large scale of the sector and the increasing introduction of new products and additional complexity also represent an increase in the consumption of energy in all the stages of the supply chain. The analysis of this consumption and the implementation of policies addressed to reduce it are essential for the sustainability of the whole logistics system associated to the food chain.

2 Energy Use Throughout the Chicken Breast Supply Chain

2.1 The Food Supply Chain

The modern food system is a complicated one, with highly industrialised processes. The methods that are used are becoming increasingly global. The globalisation of the food markets and redundancy of national borders mean that we are approaching total competition in each of the phases along the food supply chain. And, among all the technological and organizational challenges that need to be faced by food supply chains, sustainability is possibly the most relevant one.

Green et al. (2003) identified four "dynamics" that affect sustainability in food production and consumption:

- Changes to the environmental context of food production and distribution,
- Changes in economic development,
- Changes in household consumption patterns,
- Changes in technologies.

If we approach the analysis from a supply chain standpoint, we see that the chain includes a flow of materials, with information flowing in the opposite direction. The food production chain is thought to be a system of phases, each of which represents a sequence of economic activities. It also resembles a network of organisations which are economically interrelated. One important aspect of this system is that it has clearly defined limits.

Speaking in terms of innovation, this system encloses all the phases associated to economic activity. It implies changes to products, processes and the ways things are organised. The innovation may be radical or stepwise; the latter case leads to gradual improvement. In the food industry, innovation can come about as a combination of technological and organisational innovations; this combination is found in all the phases of the food production system. Earle (1997) summarised the areas in which this combination of innovations occurs:

- Food ingredients and preparation,
- Food formulation and elaboration,
- Fresh foods processing and distribution,
- Packaging,
- Retail sales,
- Food properties, including nutrition and safety.

These innovations are mainly directed at improving the economic results of food producers and retailers, and the simplest way of doing so is by developing new products. At present, product development is more important for the supply chain than process development, but the organization of the supply chain also has large effects in the economic and environmental impacts of the food industry. As a matter of fact, one important trait of the chicken supply chain is its flexibility, owing to the chicken's short life cycle (approximately 70 days).

Table 1 Aspects to consider when analyzing the impact of the supply chain

Supply chain	Factory	Process
Means of transport	Use	Operations efficiency
Factory location	Processing time	Choice of materials
Environment and health	Waste fee	Cycle length
Delivery time	Resource use	Resource use
Inventory levels	Environment and health	Environment and health

For this reason, introducing changes in the broiler poultry supply chain is relatively simple.

Three environmental parameters are used in order to discuss the role which environmental impacts play in the supply chain: water, energy and global-warming potential (GWP). Water and energy are indicators of direct consumption of the industry's inputs, whilst GWP is an indicator of the emissions created by the manufactured products. Energy and global warming potential should be considered in terms of impact on the life cycle; water, however, is a local resource, and its use does not impact the product's life cycle.

Applying resources (materials and energy) to the flow analysis for the production chain allows us to reduce its environmental impact. The main objectives of the present work are to evaluate and improve the broiler poultry supply chain on the environmental and economic levels, with special attention to energy consumption. Efforts are focused on achieving cleaner production and logistics in order to reduce the overall environmental impact of the production chain and improve economic performance. Some aspects which must be considered appear in Table 1.

2.2 Managing Energy in the Supply Chain: Methodology

Energy should be considered a business cost like any other, including raw materials and labour. Energy management requires an integrated, logical management approach which needs business decisions to be made based on energy analysis data. Once this analysis has been carried out, the energy savings may be calculated. Energy management includes planning, directing and monitoring energy supply and consumption in order to maximise productivity and comfort and minimise energy costs and pollution through the conscious, rational and efficient use of energy. The basic goal of energy management is to verify that the companies' energy needs are met at a minimum cost.

Environmental sustainability is one of the values accepted by the most competitive and successful companies. A company has to design the procedures which integrate environmental management correctly and in a way that is coherent with its long-term interests. In addition to applying cleaner technologies, companies aim to develop innovative management techniques allowing them to comply with environmental restrictions and favour sustainability. The environmental principles that are applicable to the supply chain can be categorised as follows:

- Product design: This is one of the most important tasks for any company with the responsibility of designing and developing new products and processes. These two facets are closely linked, and at the same time, they affect the environment. R&D that is oriented toward product modification and improvement can produce products with both a higher value and lessened environmental impact. As a general rule, components with a high content in recycled materials and a lower impact on the environment are preferable. Wasting materials and energy, whether due to inadequate design or to a high number of defects, must also be avoided. Renewable energy sources are seeing an increase in use, which causes a reduction in energy consumption. On the other hand, quick stripping of the product translates into cost, time and energy savings.
- Packing: Good packing design is important for a company's meeting its environmental targets. There must be a limited number of packages of each size.
- Collection and transport: Despite the obvious environmental gains from using reclaimed products, collecting and transporting these products has an environmental cost. Minimising this cost is important if we are to increase the total environmental gains. A model proposed by Samuelsson and Tilanus (1997) defines theoretical overall efficiency based on the time, distance, speed and capacity efficiency of each component in the system.
- Waste recycling and disposal: At the end of its useful life, a used product may be disposed of or recycled. As stated regarding the collection and transport phase, recycling and disposal may contribute significantly to total environmental gains and to meeting the company's environmental targets. Design is very important in recycling, but recycling becomes unproductive when the energy and materials used and pollution produced in collecting and processing used products outweigh those used and produced in fabricating the goods themselves.
- Making an eco-friendly business environment: The goal is to improve both the internal business environment (that of the company's personnel) and the external one (including providers and customers). Some of the functions that improve the environment are, for example: supplier selection, material selection, outside hiring, negotiation, purchasing, delivery planning, inventory and materials management.
- Storage: Achieving proper storage is extremely important. Correct distribution of products in warehouses is a fundamental step so that the factory will be energy-efficient; if the warehouse space is not managed well, energy will be wasted unnecessarily. The way in which different products are stacked within the warehouse is also important. Products stacked properly will occupy less space than the same quantity of products stacked improperly.
- Other management issues: These include incorporating marketing and information technology strategies, which not only add value to a product, but also increase the company's environmental efforts.

3 Description of the Case Study

We applied the evaluation of energy management in the supply chain to a case study company. We evaluated the initial status of its energy management policies according to the Energy Smart Model proposed by Tiwari and Pandey (2008), and suggested different measures to reduce energy consumption. We then evaluated the final scenario, showing the different results in the different aspects of energy management within the company's supply chain.

3.1 The Company

Our study will focus on the chicken supply chain, and more specifically, that which produces chicken breast fillets.

The company under study carries out all phases along the chicken supply and production chain, meaning it raises chicks from the moment they hatch, and then processes the chicken meat for the market.

It is a family company with plants in Madrid, Córdoba, Málaga and Jerez de la Frontera (Cádiz Province). The split chicken carcasses (slaughtered daily in the slaughterhouse in Úbeda) are distributed to the other plants, which in turn provide freshly-butchered chicken to major retail outlets, supermarkets, and traditional daily markets.

Jerez de la Frontera is home to a cutting room and facility for making prepared chicken products. This plant provides other plants with this type of product on a regular basis, using daily truck routes. Our study will be focused on the Jerez plant.

This plant has a staff of approximately 100 and a fleet of 16 delivery trucks that supply its customers on a daily basis. Split chicken carcasses, bulk chicken butchering and packing and prepared chicken products account for 90% of the company's activity. The verticality of the production process ensures that the company's products are traceable. At present, the company offers more than 50 different types of products. Its extensive catalogue of elaborated products is distributed all over Spain, and the company is known for its quality, presentation and strict control measures to ensure food hygiene and safety.

The main rooms that make up the Jerez facility are as follows: the cutting room, the prepared product room and the packing room. Each of these rooms contains the equipment necessary in order to carry out its designated activity.

In addition, the company has another line of equipment including forklifts, refrigerated rooms and refrigeration units. The facility also has a fleet of 16 trucks. Two of the trucks arrive daily from the slaughterhouse in Úbeda, and the other 14 cover the daily service routes. Apart from this, the company also has two cars used by sales representatives.

3.2 Description of the Breast Fillet Production Process

The process itself, depicted in Fig. 1, begins on the farm and ends on supermarket shelves. Our study will focus on the steps which take place within the Jerez de la Frontera plant to produce a specific product: chicken breast fillets. First of all, however, we will rapidly summarise what happens before arriving at that point.

First of all, as stated before, the process begins on the farm. The farms are the property of the company being studied, and they are located in Úbeda, Córdoba, Seville, Huelva and Badajoz. The first steps in the chicken-producing chain—selective breeding, incubation and raising chicks—take place at those facilities. When the chickens have grown, they are then taken to the slaughterhouse in Úbeda.

Chickens undergo various processes in the slaughterhouse, such as hanging, cutting, bleeding, scalding, plucking, evisceration, marking, labelling, packing and placing in pallets. Once all of the above steps have been completed, the chicken is placed in refrigerated rooms during three hours. After that, the chicken is transported from the slaughterhouse to the Jerez, Córdoba and Málaga plants. A total of 6,500 chickens are transported daily. The Jerez facility receives two trailer containers every day. Normally, the volume to be received is known one day before, although weekly forecasts are also prepared.

Once the chicken arrives at the Jerez factory, it is first taken to the warehouses. Selection for the 14 daily routes, which are always the same, takes place here. The chicken then passes from the warehouse to the cutting room. No chicken remains in storage; 100% of the chicken that arrives every day is cut up. The following steps take place in the cutting room: upending, hanging, wing removal, cutting quarters, skin removal, filleting the breast and deboning.

This study focuses on chicken breast production. Once out of the cutting room, the breast fillets continue to the packing room where it is weighed, labelled and arranged in pallets. It may be packed in various ways. One such way, which is done for only a small percentage of the product, is on bulk trays weighing between 10 and 12 kg. Another way is a set-weight tray (4 kg). A third way is to prepare variable-weight trays of approximately 300 g. In this last case, the breast is not filleted, but rather presented on the tray as two breast halves. The trays may be wrapped in one of two ways: shrink-wrapped or in modified-atmosphere packaging. The process is the same for both types of tray, but the machine used to complete the process is different. Shrink-wrapped products expire 7 days after they are packaged, while modified-atmosphere products expire after 11 days. Once the trays have been wrapped, they continue on to the finished product warehouse where the daily delivery routes are planned. Here, pallets are loaded into trucks and each of the planned routes is completed.

All of the facilities and units used in the process require some source of energy.

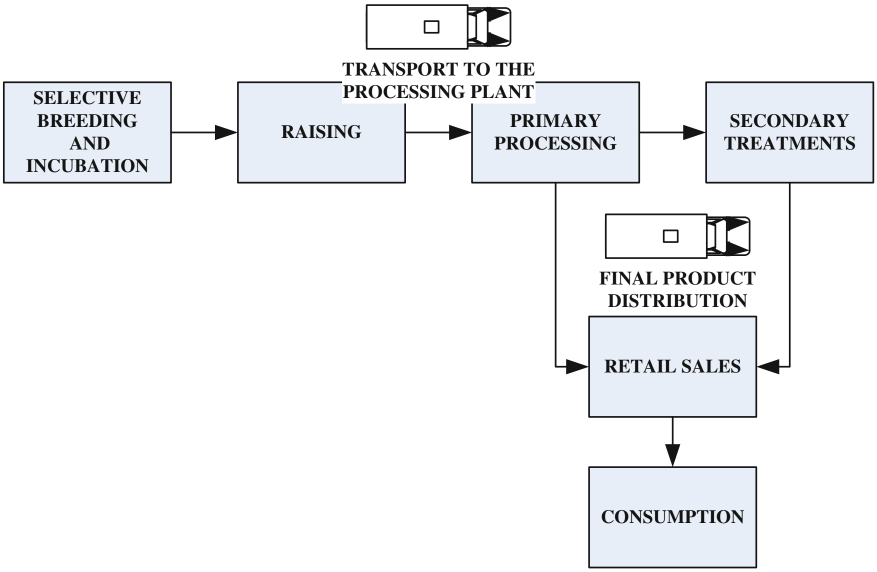

Fig. 1 Steps along the supply chain

4 Energy Analysis

Analysing the flow of resources along the production chain may be used to identify areas in which an alternative approach would foster more sustainable activity by reducing environmental impact, conserving resources, improving social benefits and improve profits.

Another goal is to use material and energy balance sheets to deduce the process and have environmental reference points that enable long-term comparison with similar national and international operations. Comparing performance data benefits the company by allowing it to apply resource-saving strategies.

Narayanaswamy et al. (2002) showed how applying resources (materials and energy) in the flow analysis for the production chain allows us to reduce environmental impact. According to their analysis, a direct method is used to analyse environmental impact in order to determine the key steps that contribute to demand and to the supply chain.

4.1 Scope of Study, Boundary Conditions and Functional Unit

The subject of this study is filleted chicken breast. A whole chicken breast makes up approximately 27% of the chicken. The rest consists of wings, quarters, skin and ribcage. The supply chain for filleted chicken breasts will be examined

Table 2 Itemised electrical consumption for the facility

Machine	Consumption (kWh)
Cone line	1.1
Dishwasher	15
Knife steriliser	0.014
Packing machine 1	4
Packing machine 2	2.5
Thermoform container machine	17.5
Shrink-wrap machine	2.65
Vacuum mixer	2.2
Weight labelling unit	0.15
Labelling machine	2.75
Electric water heater, packing room	2.5
Electric water heater, employee toilets	1.2
Forklift	8
Carcass refrigeration room	11.55
Refrigerated room for meat ageing	4.46
Refrigerated room for cut-up intermediate products	4.46
Refrigerated room for by-products	4.78
Freezer storage room 1	20.91
Freezer storage room 2	9.38
Refrigerated room for packaged products	11.55
Refrigeration unit for cutting room	28.80
Refrigeration unit for packing room	10.25
Compressed air tank	5.52
Air compressor	16.5
Oxygen pump	7.5
Air dryer	0.16
Water cooling machine	1.2

beginning with transport from the slaughterhouse and continuing to include the storage phase upon receipt, cutting room, packing room, storage of the finished product, and finally, transport along the daily routes for final use. All of these phases have to do with transport. The demand chain includes the end users or consumers of filleted chicken breast. Other possible uses of filleted chicken breast are not included in the scope of this study.

The main functional unit is defined as a unit of filleted chicken breast measured in kg. Along each step of the production chain, the available input resources and inventory data for emissions will be expressed per kg produced.

Next, we will present a list of the consumption patterns (in kWh) for all machines in the factory, as well as fuel consumption data. Water consumption of machines requiring water is also specified (in l/h).

The electrical consumption of all existing machines and units at the facility is as follows (Table 2). Next, in Table 3, we list how water use is distributed in the plant.

Table 3 Breakdown of water consumption in the plant

Unit	Consumption (l/h)
Dishwasher	60
Cone line	250
Packing room	125
Toilets and showers	80

Table 4 Summary of how different environmental resources are consumed in the chicken breast fillet production chain

Stage	Parameters	Consumption per kilo produced
1. Transport from the slaughterhouse to the warehouse	Diesel (l/h)	8.33
2. Unloading trucks	Electricity (kWh)	8
3. Storage upon receipt	Electricity (kWh)	11.55
4. Cutting room	Electricity (kWh)	58.61
	Water (l/h)	250
5. Packing and labelling	Electricity (kWh)	4.5
	Water (l/h)	125
6. Storage of finished product	Electricity (kWh)	41.84
7. Loading trucks	Electricity (kWh)	8
8. Product transport for end use	Diesel (l/h)	13.04

On the other hand, the tractor trailer that transports chickens to the Jerez warehouse from the slaughterhouse in Úbeda consumes approximately 6,000 litres of fuel/month, or 8.33 l/h. Meanwhile, the approximate consumption of each of the company's 14 trucks used for its daily routes is 8 l/100 km, calculating that completing the 14 existing routes (3,911 km/day) requires the use of 312.88 l of diesel fuel per day, that is, 13.04 l/h. Table 4 shows how different resources are consumed in the chicken breast fillet production chain.

4.2 Quantitative and Qualitative Analysis of the Chicken Breast Production Chain

It would be ideal to have a complete inventory of the emissions produced in each step along the production chain, but gathering this information is very expensive. The type of data available and the emission data collected during this study

Table 5 Distribution of energy consumption in the chicken breast production chain

Stage	Consumption (MJ)
Packing	160.2
Cutting	161.69
Storage	241.52
Transport	824.75
Other processes	173.09

determine which impact categories chosen to be included in the inventory table. The impact categories are therefore chosen according to their representativeness. In the case being studied (filleted chicken breast), we shall consider the category of global warming potential. The direct emissions from inventory data will be used to evaluate global warming.

Table 5 shows the distribution of energy consumption (in MJ) throughout the chicken breast production chain. Likewise, Table 6 shows the distribution for global warming potential (also in MJ), broken down by diesel and electrical energy.

In order to provide a direct evaluation and maintain the principle of environmental sustainability, the impact categories will be given the same importance with respect to the chicken breast production chain. Recall that the main objective of this method was to create a suitable environmental investment strategy. We seek to reduce environmental impact and achieve better economic results. This is why all types of impact are assigned the same importance, even those arising from interconnection between different categories.

Based on the quantitative and qualitative analysis of the chicken breast production chain, the area which would contribute the most to lessening the overall environmental impact would be reducing electricity and diesel consumption and the production of filleted chicken breast. Considering the type of fuel (diesel), the fuel consumption rate (8 l/100 km) and the average distance per trip, the global warming potential per unit of mass transported by truck is several times higher than it would be if transported by train. If a higher number of kg are transported over longer routes in km by train, it would be possible to reduce fuel consumption per unit of mass transported. However, economic and geographical viability, not to mention the business implications of this option, will have to be examined before making a decision based solely on environmental criteria.

4.3 Cleaner Production Potential

It can be observed from the impact matrix that global warming potential is the key factor in the filleted chicken breast supply chain. We shall investigate energy savings and improving environmental performance for that reason.

Table 6 Distribution of global warming potential in the chicken breast production chain

Source	Consumption (MJ)
Diesel	824.75
Electricity	736.5

Table 7 Breakdown of water consumption in the filleted chicken breast plant

Zone	Percentage (%)
Toilets and showers	16
Dishwasher	11.66
Packing room	24.27
Cutting room	49

- Mass balance sheet: on average, the overall performance of the product at the plant is 30.3% (in wet weight).
- Energy balance sheet: The chicken breast fillet production plant's total energy consumption (electricity and natural gas) is approximately 10257412.5 t of CO_2 in terms of yearly greenhouse gas emissions. This figure shows that it would be fitting to strive for better energy conservation by changing process logistics.
- Water balance sheet: The plant uses water, principally in the cutting and packing phases. In addition, the water used in sinks, toilets, etc. must also be accounted for. The plant uses approximately 515 total litres of water per hour. Table 7 shows an estimated breakdown of how the water is used.

5 Current Status Assessment

5.1 Methodology

Energy is the basis of and the driving force behind modern civilisation. For that reason, it is necessary to proceed with extreme care in order to use energy resources properly and efficiently. Increases in energy prices are partially responsible for inflation and economic downturn. The costs of all products have increased, but energy prices have risen more rapidly than material and labour costs. In this respect, savings associated with effective energy conservation and improving energy productivity through implementing energy management procedures that modify and reorganise equipment may help save fuel and money.

Tiwari developed the Energy Smart Model (2008) to provide specifications and guidelines for assessment in response to the pressing need for the effective management and conservation of energy. It was created by the Institute of Engineers (India) in 2003, and since then, the model has been modified for use in recent research products. The model is used for evaluating the "cleanliness" of the

Table 8 Classification of energy categories (Tiwari and Pandey 2008)

Classification	Percentage (%)
Category A	Between 70 and 100
Category B	Between 40 and 70
Category C	Between 25 and 40

company's energy according to energy smart criteria. The Energy Smart Model and assessment are based on 12 criteria. Six of the criteria refer to capabilities and the other six to results. The model also provides results in the areas of decreasing specific energy consumption, optimising resources, minimising waste, decreasing pollution, the green supply chain, use of non-conventional energy sources, process management, monitoring, measurement and continuous improvement.

It is a generic model, and therefore one that can be used with any type of organisation. Its total score is divided 50/50 (50% for capabilities and 50% for results). The first part of the study explains the model and its criteria, while the second part provides the detailed criteria used for awarding points (up to a total of 1,000). The energy category of the company being studied will depend on the percentage of the total score it receives. Table 8 below gives an approximate classification scale:

5.2 Analysis and Results

The results will indicate whether or not the company has energy management cells led by a qualified energy expert. They will also show if the company is following environmental criteria in its supply chain. Additional pieces of information to be provided by the study include whether or not providers use Energy Smart criteria, and if the company uses a recognition or reward policy with its employees. Further data which may be obtained include, for example, whether the company has achieved energy profitability, if it uses energy-saving methods or if it uses non-conventional energy sources.

Upon evaluating the company according to the questionnaire and totalling its points, the company was shown to have a score of 228 points, or 22.8%, which places it in category D. The next target will be to identify ways of improving this score so that the company can be placed in category C.

A breakdown of its score is shown in Table 9.

Using the company's score for each section of the questionnaire, we can identify areas for improvement. Some such improvements, which will be studied in the next chapter, are as follows:

- Systematically collecting and analysing energy consumption data,
- Formulating energy policies,
- Formulating energy targets,

Table 9 Evaluation questionnaire (Tiwari and Pandey 2008)

Capabilities	(126/500 points)
1. Management commitment	(25/100)
(a) Energy management policy	(0/20)
Has organisation's upper management declared an energy management policy	No
(b) Does energy management policy include commitment to:	(18/30)
Promote energy savings and resource conservation by reducing specific energy consumption	Yes
Minimise waste generation and promote reuse, recycling and disposal in an eco-friendly manner in all segments of operation	Yes
Comply with energy legislation/regulations/guidelines	Yes
Achieve continuous improvement in cost reduction through adopting an effective energy management system	No
Use renewable energy sources	No
(c) Management communicates energy management policy and energy smart criteria to the organisation	(7/30)
Is an effective system of communicating energy policy and energy smart system criteria applied to different levels in the organisation	No
Is there appropriate knowledge and visible commitment at different management levels regarding complying with energy policy and the energy smart system	Yes/No
(d) Does management determine energy smart requirements applicable to the organisation and ensure incorporation in objectives and targets	(0/20) No
2. Strategic planning	(0/50)
(a) Energy smart objectives and targets	
Energy smart objectives and targets are determined and established for relevant functions and levels of the organisation	No
Objectives are consistent with energy policy and energy smart criteria	No
Objectives are specific, measurable, achievable, realistic and time-bound (S.M.A.R.T.)	No
Energy objectives are derived based on the performance/benchmarks of similar organisations	No
Objectives and targets pursue goals of improvement at regular intervals	No
Objectives and targets are reviewed by upper management	No
(b) Energy smart system planning	
Effective planning of the energy smart system is carried out in order to meet the requirements of objectives	No
(c) Internal communication	
Communication processes are established to communicate energy smart system effectiveness	No
The communication process is effective.	No
3. Monitoring measurement and continual improvement	(33/100)
The evaluation is based on:	
Collection of data and information as per energy smart criteria	Yes
Collection of competitive benchmarks (if available) for energy smart criteria to set targets	No
Analysis of information and data on energy management from all parts of the organisation, i.e., internal consumers and suppliers	No

(continued)

Table 9 (continued)

Capabilities	(126/500 points)
Using information and data for setting priorities	No
Monitoring and measuring critical operating parameters and activities that can have a significant impact on energy management	No
Evaluating compliance with relevant legal requirements related to energy management and conservation	Yes
Taking corrective and preventive action to eliminate the cause of actual and potential non-compliance	No
Energy management system audit	Yes
Continuously improving energy performance through the use of energy policy, energy objectives, audit results, analysis of data, corrective and preventive actions and management review	No
4. Resource management	(12/50)
The evaluation is based on:	
(a) Organisational set-up for energy conservation	(0/10)
Separate energy cell within the organisation	No
Energy cell led by senior executives reporting to upper management	No
(b) Provision of resources	(12/40)
Management provides human, material and financial resources to facilitate planned improvement and achieve objectives and targets	Yes
Supply management:	
Resources for implementing the energy management system and continuously improving its effectiveness	Yes
Management provides the infrastructure needed to implement energy smart systems, including:	No
Energy efficient buildings, work plan and associated utilities	No
Process equipment (both hardware and software), plants and machinery	No
Calibrated measuring instruments	No
5. Process management	(56/150)
The evaluation is based on:	
(a) HR process	(0/25)
Recognition and rewards. How people are rewarded/recognised in order for them to remain involved with energy smart criteria in the organisation	No
How career advancement of people is integrated with involvement in energy smart criteria	No
Competency development/training (percentage of employees trained, number of training hours)	No
Motivation method employed in the organisation to direct people toward energy smartness.	No
(b) Engineering process	(25/25)
The evaluation is based on:	
Proposals of eco-friendly products with specific energy smart criteria as a percentage of the total production output. The following product aspects may be considered:	
Recycling	Yes

(continued)

Table 9 (continued)

Capabilities	(126/500 points)
More environmentally safe disposal	Yes
Use of a reusable raw materials	Yes
Efficient manufacturing	Yes
Low production and use of emissions	Yes
Longevity	Yes
Reusable packing	Yes
Large proportion of products from environmentally friendly raw materials	Yes
Large proportion of approved eco-friendly products	No
(c) Purchasing process	(3/25)
The evaluation is based on: Priority given to suppliers following energy smart criteria	
Training suppliers in the use of the energy smart criteria and system	No
Evaluating providers according to energy smart criteria	No
Green supply chain, life cycle cost and value analysis as part of the purchasing policy	Yes/No
All of the above shall be included in measurable objectives	No
(d) Production process	(28/50)
The evaluation is based on production systems, including:	
Reduction in specific energy consumption	No
Reduction in water consumption	No
Waste reduction	No
Cycle time reduction	Yes
Reduction in non-value added processes	Yes
Reduction in workplace accidents	N/A
Increase in waste recycling rates	No
Reduction in cases of occupation-related illness	N/A
Capacity utilisation	Yes
Application of modern techniques such as lean production, etc.	Yes
Including the above in measurable goals and targets	Yes
(e) Other organisational processes	(0/25)
All processes in the organisation (including administration and personnel) consider capacity utilisation, energy conservation, waste reduction and continuous improvement	No
Results	(102/500)
1. Reduction in specific energy consumption-	(0/150)
The evaluation is based on:	
Specific energy consumption vs benchmark from a similar organisation	No
Reduction in electricity consumption per unit of output	No
In electricity consumption per employee (for example, in offices)	No
Reduction in coal/oil/gas consumption per unit of output	No
Reduction in specific energy consumption according to established objectives and targets	No
Reduction in proportion of energy costs to operations costs	No

(continued)

Table 9 (continued)

Capabilities	(126/500 points)
2. Resource optimisation	(62/100)
The evaluation is based on:	
Efficient use of raw materials, water, energy, etc	Yes/No
Proportional reduction in production costs by reducing consumption of materials	No
Reduction of environmentally hazardous input materials	N/A
Reduction of environmentally harmful input materials (solvents, dyes, etc.)	N/A
Replacements with more environmentally-safe alternatives (e.g. Renewable raw materials, reusable packing, recyclable raw materials, solvent-free paints and varnishes.)	Yes
Incorporating eco-friendly, biodegradable health and safety criteria when evaluating input materials	Yes
3. Waste minimisation	(40/100)
The evaluation is based on:	
Reduction in the total amount of waste from production processes	No
Reduction in waste from processes other than productio	No
Reduction in proportion of waste for disposal to waste for recovery (recyclable waste)	No
Reduction in specific waste or waste per unit of product (in kg/tonnes)	Yes
Paper waste per employee	N/A
Reduction of waste transportation costs	Yes
Reduction in hazardous waste in proportion to total waste	N/A
4. Reduction in pollution	(0/50)
The evaluation is based on:	
Reduction in air pollution due to toxic air emissions	No
Reduction in process emissions with odour-causing gases such as ammonia	No
Reduction in hazardous waste	N/A
Reduction in greenhouse gas emissions	No
Reduction in polluted water (water polluted in production process, sanitation waste, etc.)	No
Reduction in the degree of pollutant concentration in waste water	No
Improvement in disposal to make it more environmentally safe	No
Reduction in pollution from transportation	No
5. Green supply chain	(0/50)
Number of suppliers who have energy smart system criteria, at least partially	No
Energy smart system evaluation carried out by provider (%)	No
Proportion of purchased goods from suppliers implementing energy smart system criteria	No
6. Use of non-conventional sources of energy	(0/50)
The evaluation is based on:	
Promotion of “clean and green energy” in all areas of the organisation	No
Making energy-efficient buildings to conserve energy	No
Making investments in harnessing various renewable energy sources	No
Undertaking an awareness-raising campaign for employees	No

- Fostering staff participation in improvement processes,
- Benchmarking,
- Investing in infrastructures (for example, covered bays for trucks),
- Optimising routes,
- Managing warehouses properly.

6 Recommendations for Improvement

These improvements are intended to improve the company's energy performance and therefore increase its score on the questionnaire. Meanwhile, following the visits to the plant in which its functioning and distribution were observed, another series of improvements may also be suggested. If they are carried out, they will also have a positive effect on overall energy performance.

6.1 Systematically Collecting and Analysing Energy Consumption Data

The first step to be taken with a view to improving the company's energy performance is to collect all consumption data systematically and analyse it.

Some degree of environmental impact occurs at all steps along the supply chain. This is why we must clearly identify all stages in the product's life cycle, since any process in the supply chain may have a negative impact on the environment.

Once the internal workings have been analysed, we see that the company's electrical consumption data is not collected systematically. These data must therefore be measured, organised according to the stages of the production chain, and then analysed. The analysis will allow us to identify which phases consume more energy and which phases consume less. This provides information about which stages require intervention the most urgently in order to improve energy efficiency, as we will know which steps waste more energy than others.

6.2 Formulating Energy Policies

At present, the company undergoing study has no energy policy since its upper management has not pronounced on any energy policy that must be followed. Implementing this type of policy in the company may help reduce environmental impact, since employees at all levels would then have a model to follow and a policy to which to adhere. In addition, there would be a communication system between the different levels of the company, and the better-defined the energy policy, the better the communication system would be. If all employees were aware of the policy, compliance with it would help the plant's overall energy performance.

All energy policies are associated with a series of targets or objectives. This could be another potential improvement, and it is analysed in the following section.

Both this area for improvement and the two subsequent ones can be governed by UNE-EN standard 16001, which specifies the requirements for establishing, implementing, maintaining and improving an energy management system. The system is mindful of the legal obligations which the company must meet, and allows it to adopt a systematic approach to continuously improving in matters of energy efficiency.

According to this standard, the company's upper management must establish, implement and maintain the company's energy policy, ensuring that the energy policy complies with a series of standards.

6.3 Formulating Energy Objectives

Just like the energy policy, energy objectives must be established by the company's upper management and they should be determined according to different levels within the organisation. Obviously, these objectives or targets must be coherent with the established energy policy, and their end goal is to bring about improvement.

Some of the energy objectives which might be established are as follows:

- Promote energy efficiency and energy savings,
- Increase production and use energy sources that generate less pollution.
- Reduce the environmental impact of production and use of energy sources.

According to UNE-EN standard 16001, the organisation must establish, implement and maintain documented energy objectives and targets for all applicable positions and levels within the company.

The objectives must be coherent with energy policy, including commitments to improve energy efficiency, and they must comply with pertinent legal obligations. The company must establish specific objectives for all controllable parameters that have a significant impact on energy efficiency. Energy objectives must be measurable and documented, and there must be a deadline for meeting them.

6.4 Fostering Staff Participation

Another possibility of improving the company's energy management is to encourage all staff to participate in saving energy.

The company may well establish an energy policy and energy objectives, but this serves no purpose if the company's staff do not contribute to achieving these targets. All of the different levels of the company must participate in the implemented policy in order to successfully improve a range of processes, thereby saving energy.

To this end, staff will need to undergo skills development or training sessions. According to UNE-EN standard 16001, the company must be certain that its employees understand both the energy policy and their functions and responsibilities in order to comply with the energy management system requirements, in addition to the benefits of improved energy efficiency.

6.5 Benchmarking

At present, our company does not undertake benchmarking, so it does not have energy consumption data for its competitors. If this practice were launched, we would then understand our company's placement within the filleted chicken breast market. Based on this step, a range of actions could then be carried out in order to reduce consumption and improve energy performance. Benchmarking requires concerted effort on the part of upper management when results clearly indicate which measures will bring about improvement.

6.6 Investing in Infrastructure

There is yet another possibility for improving the company's energy efficiency. This option is to invest in infrastructures that will improve performance over the long-term. Taking on investments may incur an additional cost to the company in the short term, but the company can enjoy benefits and improved energy efficiency in the long-term. In any case, investment should be balanced, reducing infrastructure spending as much as possible, but investing in the infrastructures that are necessary to improve the company's energy performance over time.

One example of such an investment would be building a covered bay near the loading docks to keep trucks in the shade. The company's fleet of vehicles currently has no shelter from the sun. This leads to an increase in their temperature, especially in summer, which is detrimental to food hygiene and is also wasteful of the energy that has to be used to keep the trucks' refrigeration chambers cold.

Another potential investment would be insulating the warehouse. The warehouse has no insulation at present, which naturally leads to temperature variations from room to room. The company is part of the food industry, and its products must be kept at a certain temperature so as to maintain them in perfect condition. Since the warehouse is not insulated, the company must use more energy to reach those temperatures than would be necessary if the warehouse had insulation. In the long term, the decrease in energy consumption would be significant, and accompanied by economic savings and improved energy performance.

6.7 Optimising Routes

Transport is a fundamental part of the supply chain; without it, the different stages along the chain cannot be completed. At the same time, it is a notorious contributor to negative environmental impact, and large-scale efforts are needed to mitigate that impact as much as possible. To that end, appropriate logistics management tools for optimising routes must be located. Logistics performance may improve through route optimisation, proper transport coordination and other integrated logistics methods.

Route optimisation refers to improving the distribution of trucks' journeys from point to point along the network, taking into account the vehicle's load capacity, loading time and delivery location.

Transport coordination itself can generally be undertaken in two ways: through backhauling and combined loads. The first means of coordination is based on using the empty capacity during return trips to move products in several directions, and the second refers to using capacity to move goods in a single direction. It is also possible to use a method combining both approaches, and this is the most effective way to proceed. If there is proper coordination for all stages along the supply chain that require transport, such as transport to the farm and the slaughterhouse, transfers to the plant and delivery to retailers, the number of trips can be reduced by up to 40%. With respect to route optimisation, if a multiple-route system is established, it could save time by a factor of between 15 and 25%.

Normally, the JIT (just in time) method is used for hauling goods when deliveries are small and frequent. Our study shall use this method, given that the product has a relatively short life cycle. Owing to the use of JIT, increasingly lighter trucks are being used. Effective use of truck capacity depends not only on the loading rate, but also on the load variation rate during transit and times when the truck is running empty. On the other hand, it should be stated that efficiency can be defined in economic terms (diesel consumption savings) as well as in terms of environmental effort (improved energy efficiency) (Ljunberg 2006).

During loading and unloading operations, a list of data must be recorded, including the truck registration number or the transport company name, the delivery address, the truck's arrival and departure times, the waiting period, the time to load or unload, the number of pallets moved and the type of product transported.

6.8 Warehouse Management

The main improvement to be made to the plant is perhaps implementing a proper warehouse management system.

The company possesses different warehouses for received products, products being processed and for the range of finished products, with separate chambers for frozen products.

The first observation that can be made is that space in the refrigerated rooms and warehouses is underused. As a result, more energy is used to maintain the warehouse temperature than would be strictly necessary. Empty space is being left in the warehouses, and it has to be kept cold as well as the products. If more products were placed in the refrigerated rooms, the same amount of energy could be used to keep larger quantities of product cold than is currently the case. A good solution to this problem would be to install shelves, which the company does not currently use. Products could then be stacked higher, leaving room to place more products in the same room. One possibility that bears investigation would be stacking pallets two-high. The pallet which the company currently uses is the Europallet, which has a flat surface of 800 × 1,200 mm and is 15 cm high. Each pallet holds 40 boxes with dimensions of 550 × 365 × 186 mm and weighing 1,350 g. Therefore, each pallet level holds four boxes. A simple arithmetical calculation shows that the total height of a pallet with all of its boxes stacked up is 2,010 mm, that is, approximately two metres.

The height inside the plant's warehouses and refrigerated rooms is four metres. This means that given the way pallets are currently put together, it is impossible to stack pallets on top of each other to form a double row; they would exceed four metres in height, which is the height of the warehouse ceiling. There are two potential ways of correcting this problem. The first would be to stack fewer boxes per pallet. Instead of stacking 40 boxes per pallet, 10 boxes high, pallets could be prepared with only 36 boxes to reduce height by one row of boxes. This would give a total pallet height of 1.824 m, permitting one pallet to be stacked on top of the other; the total height would thus come to 3.648 metres, which would clear the ceiling. By using this strategy, there would be four fewer boxes per pallet, but each warehouse would hold double the number of pallets it held before. Storage capacity would therefore be increased considerably. The second option for solving the height problem would be to use another, slightly lower type of pallet than the one currently in use, although such a pallet would likely be difficult to obtain. It might also be possible to find flatter boxes than the ones currently in use.

In addition to stacking pallets two-high in warehouses, it may also be possible to use this strategy when loading trucks to use as much of their capacity as possible. In this case, we will have to take into account the truck's MAM or maximum authorised mass, as it may be possible to load the truck with more pallets by stacking them two-high, but they cannot be hauled if the truck's maximum load capacity is exceeded. Keep in mind that a vehicle's useful load is the difference between its MAM and its empty weight. The company's trucks have an MAM of 5,600 kg and an empty weight of 3,100, and therefore the maximum load transportable by each truck may not exceed 2,500 kg. On the other hand, truck trailers have a ceiling clearance of 2.45 m. If we recall that the full height of a pallet loaded with 40 boxes was 2.01 m, we see that there is a 44 cm space between the pallet and the ceiling. This means that it is impossible to stack pallets two-high inside truck trailers.

In the same way, the way in which pallets are stored will also affect the number of them that fits in the warehouse. Good organisation means that more pallets will fit, while if they are placed at random, usable space may be wasted.

Another possibility for improving energy performance through proper warehouse management would be by grouping similar products in the same refrigerated room. The refrigeration units are always switched on, even when rooms contain only small quantities of products. This wastes energy unnecessarily and could be remedied by placing the small quantity of products in another, fuller refrigerated room containing similar products. Some of the refrigerated rooms in the factory are nearly empty most of the time. These include the turkey and hen products room and the by-products room. Since these refrigerated rooms contain so much empty space, they waste vast amounts of energy. In this case, if possible, these products could be placed in refrigerated rooms housing other similar products, as stated above, leaving their original rooms unused and switched off. This would save energy. If due to any legal reasons it is impossible to transfer these products to another refrigerated room, the room could be divided in two and insulated properly. In this way, the capacity of the rooms would be reduced by half, and this would permit significant savings in electricity. This approach could also be considered as an investment in infrastructure.

The case of frozen foods is similar. The plant has two freezer rooms which must be kept at −20°C. However, much of the space in both of the rooms is wasted, and therefore all frozen products could be placed in the same room, thereby preventing one of the rooms from consuming electricity.

In summary, a good method for improving the plant's energy performance would be to switch off underused refrigerated rooms and store products in the remaining refrigerated rooms according to product similarity whilst taking care to comply with all health and safety regulations.

7 Final Status Assessment: Foreseeable Changes

Once the improvements specified in the previous section had been put into place, the Tiwari method was applied once more to assess its new status. The company was evaluated using the Energy Smart Model questionnaire and received a score of 355 points, that is, 35.5%, meaning that the company is now classified as category C. It has undergone considerable improvement (127), since prior to the changes the company was classified as category D, with 228 points. A breakdown of its scores, with improvements that led to its new classification in bold, is shown in Table 10.

Table 10 Scores broken down before and after improvements

	Before	After
Capabilities	126/500	228/500
1. Management commitment	25/100	60/100
a) Energy management policy	0/20	20/20
b) Sections included in the energy management policy	18/30	18/30
c) Management communicates energy policy to the organisation	7/30	22/30
d) Management determines Energy Smart requirements applicable to the organisation	0/20	0/20
2. Strategic planning	0/50	22/50
3. Monitoring, measurement and continuous improvement	33/100	66/100
4. Resource management	12/50	12/50
a) Organisational set-up for energy conservation	0/10	0/10
b) Provision of resources	12/40	12/40
Process management	56/150	68/150
a) HR process	0/25	12/25
b) Engineering Process	25/25	25/25
c) Purchasing Process	3/25	3/25
d) Production Process	28/50	28/50
e) Other organisational processes	0/25	0/25
Results	102/500	127/500
1. Reduction in specific energy consumption-	0/150	25/150
2. Resource optimisation	62/100	62/100
3. Waste minimisation	40/100	40/100
4. Reduction in pollution	0/50	0/50
5. Green supply chain	0/50	0/50
6. Use of non-conventional sources of energy	0/50	0/50

8 Conclusions

The first part of this study presented an introduction to the food supply chain, and the filleted chicken breast chain in particular. It discussed the methodology used to evaluate energy consumption, and the different approaches to completing the study. It mentioned the economic structure of the chicken market worldwide, and included a schema of the chicken supply chain that defined each of its stages. It then commented on the implications which the supply chain processes have on sustainability.

We then applied the analysis to a case study company. After describing the company, we listed the different products that it produces and markets before explaining the processes carried out in the chicken production chain. We emphasised the phases that take place in the plant itself, in addition to the transport phase from the slaughterhouse to the plant, and from the plant to the points of sale.

After having described the company, the study aimed to show that innovation in the food industry may be seen as a combination of technological and organisational innovations. It spoke of those innovations and of different factors that must be taken into account. Next, energy management, another important aspect of logistics, was analysed. The study argued that energy should be considered a business cost like any other. To support that argument, different aspects of energy management and steps to follow to implement an energy management policy were discussed. Sustainability, which is closely related to energy management, was another key topic. The different environmental principles applying to the supply chain were then categorised.

We also completed an energy analysis for the company. We measured energy consumption (electricity, diesel and water) for the different steps along the production chain. Once all of the data was measured and duly categorised, the stages incurring in the highest energy use were indicated.

We then used the Energy Smart Model, developed by Tiwari and Pandey (2008), to evaluate the company's energy status. This model is based on different criteria and assesses a company through the use of a questionnaire, resulting in a score that can be used to categorise the company. The higher the score, the better the use of energy within the company. The company received a score of 228 points, or 22.8%, during the first assessment, which placed it in category D. Given the result, the goal became to search for potential means of improvement that would increase the score and place the company in a higher category. One very positive aspect of the Energy Smart Model is that it enables us to identify areas in which the company can improve.

We addressed the main issues highlighted by the Energy Smart Model through the identification of potential areas for improvement. The improvement strategies were identified through using the questionnaire and through different visits to the plant itself. We formulated different improvement strategies and estimated the advantages derived from implementing them.

Lastly, after an analysis of the improvements that may be made in the company, the Energy Smart Model was again applied by filling out the questionnaire a second time. The goal of the project was to identify potential improvement strategies that would improve the company's energy efficiency. For that reason, we expected the score to be higher the second time the method was applied. As anticipated, once the questionnaire was filled in, the score added up to 355 points (35.5%), placing the company in category C. Our objective was therefore achieved: the company's ranking went up by one category, which implies that its use of energy has improved significantly.

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The Railway as a Key Element of Sustainable Tourist Development in a Rural Area of Difficult Access: Application to a Spanish Mountain Resort

María-del-Val Segarra-Oña, Ángel Peiró-Signes, Lluis Miret-Pastor and María de-Miguel-Molina

Abstract Despite the ongoing threat faced by rural railway lines, *Vall de Núria (Spain)* has been able to use the rack railway to develop a tourism model that combines cultural experiences, religious, sports and environmental management clearly oriented towards sustainability environment, mainly due to that the rack wheel railway has remained as the only means of mechanical transport to access the valley allowing a sustainable tourism growth. In this chapter, a detailed description of the sustainable tourism model at *Vall de Núria*, which has adopted self-regulatory practices in environmental issues outside the regulatory requirements enabling you to improve its competitive position as environmentally friendly tourist destination, adding value to their products and improving its image as well as of the close relationship with the railroad system of rack railway.

Keywords Vall de Núria · Rack railway · Sustainable tourism

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1 Introduction

The lack of inland waterways, unlike other neighboring countries, stimulated the introduction and subsequent development of railways in Spain. After England and France, Spain had in the late nineteenth century the third European rail network, despite it had arrived in Spain with an average delay of 10–20 years in relation to the main European countries (Cuellar 2007). The railroad from the beginning was a development symbol and a technological progress and represented an essential way of transport during the first half of last century. However, the popularization of car use by families and the road infrastructure improvement has led to a sharp decrease in the number of passengers and goods transported by train in recent decades.

In this situation, the rail network expansion and the preservation of railway heritage were threatened. It was in England where it began a new use for the rail network in the late 1970s through the creation of spaces in the stations and their surroundings for social and cultural interaction, raising a tourism product around the railway (Verbeek and Mommaas 2008).

Moreover, to achieve sustainable development, the OECD (2001) developed a set of criteria which pretend for tourist transport, at least in the future and among other issues, to be driven by renewable energies, to be built with renewable resources and to avoid the creation of waste or the irruption on the animals and people natural flows, as noted Morante (2009).

2 Sustainable Tourism and Transport

Brundtland report (1987) expressed the concept of sustainable development as the important idea that we have to meet our needs without compromising the ability of future generations to meet their own needs. The concept of sustainable development is closely linked to sustainable tourism (De-Miguel-Molina and Segarra-Oña 2010), especially in areas where tourism is an important part in wealth generation. Several studies have demonstrated that tourist travel is a major source of serious environmental problems (Høyer 2010).

Sustainable tourism requires nature and culture preservation of the tourist destination and of the region, while ensuring the traceability for products and services that offer the visitor's experience (GösslingLaw and Peeters 2007). The whole process should take place with the governmental, private and civil partnership and must be driven by a sustainability monitoring system to enable policies and strategies establishment (Morante 2009).

The social and economic development has had all around the world a dramatic increase in people's mobility that, in general, has contributed to improve our quality of life. But this growth has also increased our dependence on petroleum and it's causing serious environmental pollution problems (Weaver 2010).

There is also a strong imbalance in the participation of different transport modes in total mobility, with a stranglehold of the road transport and, in particular, with the leadership increase of private vehicles. Per passenger-kilometer car consumes more than other passenger transport vehicles (train and bus). Although there has been a significant reduction in car consumption due to technological advances, this is compensated at the same time by the acquisition of bigger and more powerful cars and increase in the use made of them (Gössling et al. 2002).

Nowadays, there isn't a viable technology capable of limiting the emission caused by the use of fossil fuels so that the efficient use of public transport to solve people movement in general and tourist movement in particular is especially interesting if a pollution reduction is wanted (Ballester and Peiro 2008).

A wide range of publications have shown that tourist industry is increasingly environmentally unsustainable (Mondéjar-Jiménez et al. 2010). This is mainly due to the contribution to the increase in greenhouse gases of some modes of transport (mainly air) used for a tourist purpose (Peeters et al. 2006). The trip currently represents between 50 and 97.5% of total emissions impact of most tourist trips (Dickinson et al. 2010), so one of the challenges of the tourism industry is to provide tourism with a more sustainable transport component from the environmental point of view (Kelly and Williams 2007).

Sustainable transport for tourism is an under-researched topic, however, transportation is the way to reach and to move within the destination (Burkart and Medlik 1981), therefore it is a fundamental part of tourist system (Page 2005), both as a facilitator of the access to tourist destinations and as an essential part of the tourist experience by itself.

An area with tourist attractiveness requires of an infrastructure and a transportation network for its development. The railway encouraged the development of the first spa resorts and seaside resorts (Sancho 2005) and allowed the commercial; tourist and culture revitalization of these destinations and, simultaneously, the growth of tourist demand and their requirements have also influenced the development and quality of transport services.

As shown above, the organization and use of local resources, the recovery of cultural and historical heritage, the infrastructure improvement and the supply expansion require tourist plans (Vargas-Vargas et al. 2010). This planning is usually done locally and typically is included in a larger scale planning, usually at regional level covering social, economic and cultural scales. Within this planning, a key role is played by public institutions and their tourist development policies that allow to allocate resources to the cultural, historic and environmental heritage recovery and to promote the tourist development of a specific site, while generating direct and indirect employment opportunities (Alberdi 2004). However, public policies in the Spanish countryside have been scarce, discontinuous and uneven (Gonzalez 2004).

In any case, this development is particularly interesting for the recovery of rural areas, affected by abandon, depopulation and the loss of traditions, and has allowed the environmental awareness of the urban society. The accessibility improvement of rural areas improves integration throughout the territory and, moreover, the opportunities to become a spot for leisure and traditions preservation (Cánoves et al. 2004) and for new adventure sports (Lacosta and Canòves 2003).

Ensuring sustainable development, that is, the rational growth without destroying landscape, social and cultural resources in the long term, rises as a benchmark element in the tourist framework (Espejo 2004) and thus its necessary to analyze and evaluate previously the possibilities of each destination for each type of tourism (Ocaña et al. 2004; Sayadi and Calatrava 2001), considering, moreover, that saving energy is a key aspect for a sustainable company like RENFE (Guisasola 2008).

A good tourism management requires sustainability guarantee of the resources on which it depends (Rivas and Magadan 2007), that is, tourist activities must be respectful with the natural, cultural and social environment, allowing users to enjoy a positive exchange of experiences among residents and visitors, where the benefits of the activity are distributed equitably, and where visitors have a pro-active approach to their travel experience (Prillwitz and Barr 2011).

Therefore, tourism should provide an acceptable evolution in its impact on natural resources and the assimilative capacity of the impacts and residues produced, also considering the impact on cultural heritage and traditions of local communities (Segarra-Oña et al. 2011c).

In this sense, the recognition of local culture and interests represents a starting point for the formulation of tourist strategies and projects, from which create and develop tools for integrated planning and management that can contribute to local economic development and the quality of life improvement of the population (Perch-Nielsen et al. 2010). Consequently, the alternative forms of tourism promotion by the government and the tourist industry consistent with the sustainable development principles as well as the diversification of tourist products promotion, will guarantee medium and long term stability (Peiro-Signes et al. 2011).

Codes of conduct adoption that take into account environmental protection can be effective tools for responsible tourist activities development.

Special attention must be paid pay to transport role and its effects on the environment in tourism as well as the development of tools and measures to reduce no renewable energy and resources use (Ventosa 2009) fostering at the same time the recycling and waste minimization in tourist facilities (Charter for sustainable tourism Lanzarote, 1995).

Although according to some authors like O'Toole (2008), some rail lines, far from protecting the environment, use more energy per passenger km, and therefore generate more greenhouse gases than cars do when as a complement to the transport operation, it is necessary to make connections with off-peak buses. It has to be added to this that the rail lines construction consumes huge amounts of energy and emits large amounts of greenhouse gases. In this sense, the exploitation or rehabilitation of an old infrastructure represents an important saving in the environmental impact over the construction of new infrastructure, as emissions of CO_2 kgs per km and passenger of railway transport is between 2 and 3 times less than the ones emitted by cars (see Fig. 1).

This chapter analyzes the case of "La Vall de Núria" like the paradigm of sustainable tourism as a result of differential transport system, the rack wheel railway. The Vall de Núria study shows the evolution of a destination towards

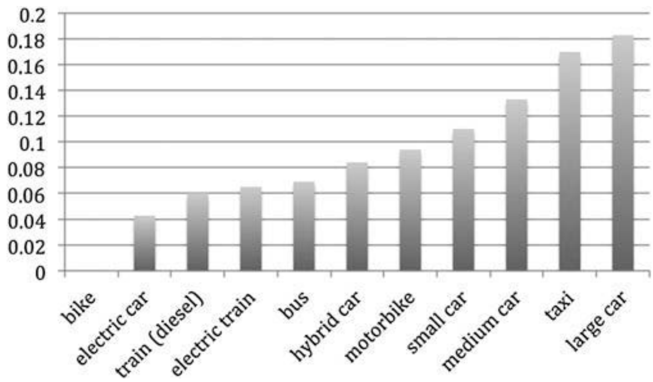

Fig. 1 CO_2 emissions by mean of conveyance. *Source* 2008 Guidelines to Defra's GHG conversion factors: methodology paper for transport emission factors

environmental sustainability out of patterns of behavior shown by other destinations. This destination has been able to integrate cultural, religious, environmental and sports aspects excellently forming an attractive tourist destination while respecting the environment from the rack railway line built in the first half of last century (Sola 2006).

3 The Vall de Núria Case. History and Tourist Attraction

Located in the Eastern Pyrenees, within the municipal area of Queralbs, province of Girona, and in between mountains of almost 3000 meters, Vall de Núria offers year-round tourism with a variety of activities in harmony with the environment.

It's remarkable that the resort is managed by the *Catalan Railways Tourism and Mountain Division*, being maintenance and respect of the environment a constant concern in any action taken on the facilities, services, buildings or the environment itself.

The birth of the rack railway project dates back to the first third of the twentieth century in response to maintenance needs and access to the Sanctuary and to the first sports movements in the area around the hiking and skiing. After shuffling some alternatives (mainly, road and funicular), the rack railway was begun in 1926. In 1927 *Ferrocarriles de Montaña a Grandes Pendientes* (FMGP) responsible at that time of the Montserrat rack train, became Nuria railway operator by Royal Decree. Construction began in 1928 and then it had a large impact on employment in the area (800–1000 employees). After several years of work it was on March 22th 1931 when the rack wheel railway and years later, in 1953, may terminate the work with the building of the station Nuria. Later on, various works to improve the course and facilities were carried out during the 1980s.

Table 1 Details of the Nuria Valley rack railway

Vall de Núria	
Rack railway length (km)	12.5
Double or articulated vehicles	6
Locomotives	3
Lounge cars	7
Trails	11
Trails length (km)	8
Lifts	7

Source Solá 2006

Note that after the floods that hit the valley in 1982, the Catalonian government took over the operator and in 1984 the Nuria rack railway became part of *Ferrocarrils de la Generalitat de Catalunya*. In the 12.5 km travel rack railway overcomes a height difference of 1058 m with a maximum gradient of 15% crossing viaducts and tunnels. The line has 4 stations and a halt, with vehicle access only possible to Queralbs station located approximately half way. Table 1 presents data on the Nuria Valley rack railway.

Both building architecture and rack railway convey harmoniously into the landscape, near the Sanctuary, constructed around the image of a virgin found by shepherds. The Nuria Sanctuary has played a key role in the evolution of the destination. In addition, Saint Gil and Amadeo's caves, San Gil's hermitage, the religious festivities and the monumental via crucis represent the cultural, historical and religious attractive of Nuria.

The current architecture comes from the architectural remodeling of the site during the first half of the twentieth century mainly driven by the will of the Urgell's bishops. At this time, hiking, winter sports got expanded and the construction of the lake was carried out, allowing the development of other sports and leisure activities like fishing, boating, kayaking, etc.

Vall de Nuria, because of its geographical location presents wildlife features similar to other European mountain sites, but also lives in both animal and plant species endemic to the Pyrenees, giving an environmental and landscape interest that has been for years a tourist attraction. This environment, which is watered by creeks and springs, is protected as a game reserve and is included in the Plan of natural areas in Catalonia (PEIN).

The valley also offers gastronomy derived from traditional activities from mountain areas with special emphasis on the use of natural products that, together with the restaurant development ensures a quality of cuisine from the area in line with site expectations.

The Vall de Núria appeal extends to its immediate environment, the Ribes Valley, which is a rural setting with ideal environment and landscape for walking and hiking. Valley peaks and viewpoints let tourist enjoy the landscape and the valley municipalities offer other historical, cultural and religious attractions that increase the tourist supply of the destination.

4 Development of Tourism in Vall de Núria

As noted above, rural railway lines were reduced severely in the second half of last century in England (Simmons and Biddle 1997) and this process has been repeated over time in many European countries as a result of the road transport growth. However, despite the ongoing threat faced by rural railway lines, Vall de Nuria has been able to use the rack railway to develop a tourist model that combines cultural, religious, sports and environmental experiences with a clearly oriented management towards environmental sustainability.

It is necessary to emphasize the balance established in Vall de Núria between the politics of keeping the rack railway as the only mechanical form of transport to access the valley and the proposed solutions for sustainable tourism growth without jeopardizing the economic benefits of tourism.

Vall de Núria has gone beyond environmental regulatory requirements adopting self-regulatory practices that allow improving its competitive position as environmentally friendly tourist destination, adding value to its products and improving its image (Forsyth 1997).

As raise the evidence that the uncontrolled growth of tourism may create unwanted social and environmental impacts in tourist destinations, there is a growing interest to develop an environmental regulation to reduce these effects by the authorities, and at the same time let maintain tourist industry viability.

To avoid environmental or cultural damage of tourism, operators and planners have to cooperate with government authorities and businessmen from other industries to establish planning strategies and other mechanisms to ensure that tourism won't exceed the capacity of the destination (Manning and Dougherty 1995).

Planning should facilitate decision-making at every level in order to achieve the expected results in the short, medium and long term.

Rack train management in Vall de Núria has succeeded in integrating tourist and transport activities in the valley ecosystem according to improvement, conservation and respect for the environment criteria (Sola 20060. In this line, Vall de Núria has voluntarily adopted an environmental management system based on ISO 14001, allowing to have a management tool that can prevent pollution, fulfill current legislation and what is more important, enable continuous improvement and the introduction of an eco-innovative environmental management system (Segarra-Oña et al. 2011a).

Besides energy saving and other actions like environmental flows maintenance, water consumption cut offs, environmental restoration (vegetation) and landscape integration are remarkable and require workers and visitors commitment, strengthening the bond with the environment of both.

To achieve this linkage is necessary to inform and to aware workers and visitors of the values of environmental respect and preservation. For this reason, Vall de Núria allocates part of the facilities and activities to environmental knowledge. Nature's Classroom, case information points located at the key points, ride signaling, the tour guides, the library, permanent exhibitions and educational

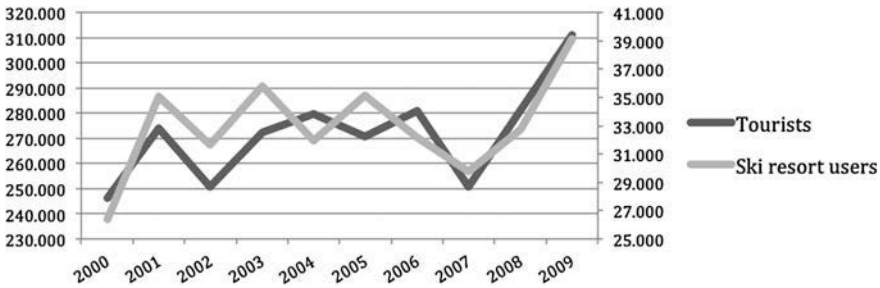

Fig. 2 Number of visitor's evolution to Vall de Núria, 2000–2009. *Source* Compiled from data published in the annual reports of FGC

workshops are clear examples of the importance of the work being done and of the inseparable union of history, nature and sport in this Valley.

During winter season, Vall de Núria ski resort starts working. It has been awarded with the Q rating for quality granted by the Spanish Institute for Tourist Quality that demonstrates the resort commitment to achieve full customer satisfaction and service excellence, ensuring further compliance with the Quality Standard of Services. The Q rating for quality is a brand of the Spanish Institute for Tourist Quality. More than 2000 facilities have been certified and it is beginning to be recognized nationally and internationally, bringing prestige, differentiation, reliability and rigor to certified tourist establishments (Miret-Pastor et al. 2011).

The Q rating for quality indicates that the establishment follows a series of written and formalized procedures that helps on one hand, to measure the quality of its services according to the norm, and on the other hand, to satisfy customers and to plan and carry out continuous improvement strategies deemed necessary to achieve product excellence, and thus, to improve its competitiveness.

Moreover, the Q rating is used for promotion and marketing purposes, allowing a new vision of the establishment as a "whole".

The special characteristics of the accesses and the ski resort size makes its characteristic family atmosphere, away from other destinations in the Pyrenees more overcrowded, without losing quality in essential services (equipment rental, medical assistance, restaurants and accommodation, ski school, etc.) demanded by visitors to ensure satisfaction in winter sports practice (López 1996).

The connection to the rest of the rail network is done through the Ribes-Enllaç station, which links to the Spanish and Catalan railway network and to ensure access for those tourists using the car as transportation free parking areas in different stations have been enabled. La Vall de Nuria is progressively increasing the number of visitors. (See Fig. 2).

La Vall de Nuria is a unique case in finding an excellence model for transport and tourist operations management. Innovation, modernity and respect for the environment are the bets that the manager of this infrastructure, Ferrocarriles de la Generalitat (FGC) is taking and those that are allowing growth and valley evolution as a sustainable destination.

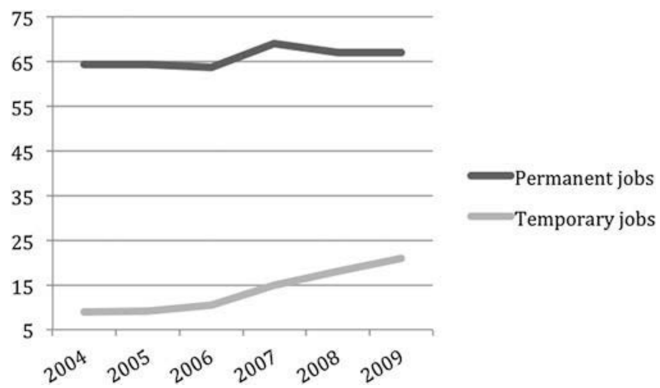

Fig. 3 Evolution of permanent and temporary jobs, 2004–2009. *Source* Compiled from data from the annual reports of **FGC**

The strategy is oriented to efficiently and effectively manage services and infrastructure, intending to give the public a set of leisure services that meet customer expectations. This strategy forces, without neglecting the pursuit of economic efficiency, constant innovation, environmental respect and corporate social responsibility (CSR) emphasis, as FGC is a public company that operates transportation and leisure services financed with the proceeds of the business activities and the contributions made by the Administration.

Moreover, both transport activity and tourism are real economic development engines, revitalizing direct and indirect activities within their area of influence, such as hotels, catering, and trading (Herranz 2002). In Vall de Núria both, sports and cultural tourism generating direct and indirect jobs in real estate and hospitality businesses, especially permanent ones, associated with the seasonal business, as shown in Fig. 3.

To ensure sustainable tourism, the search for this social profitability forces, among others, to minimize negative impacts and unintended consequences that may arise exercising business activities, to have attitudes focused on sustainable development and environment respect and to improve continuously the processes (Valdés et al. 2002)

5 Vall de Núria Environmental Orientation

Actions taken in Vall de Núria to achieve sustainable development cover both technical and management aspects of transport and leisure services, among which are:

- Reducing noise and vibration emissions.
- Reducing greenhouse gases emissions.
- Energy saving systems and consumption reduction implementation in trains.

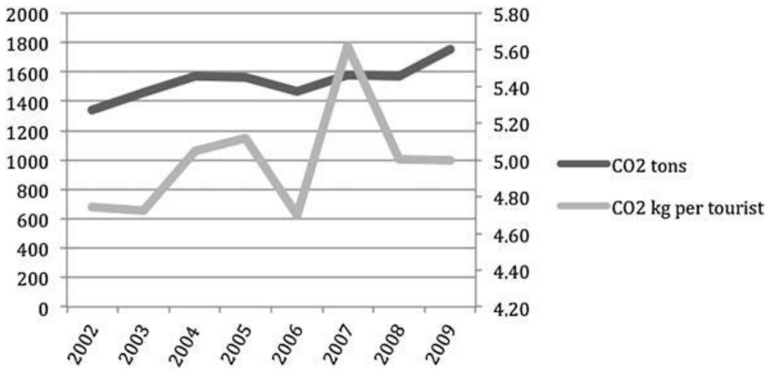

Fig. 4 Vall de Nuria CO_2 consumption 2002–2009. *Source* Compiled from data from the annual reports of FGC

- Energy saving systems on facilities (geothermal energy for heating water and presence detectors to light consumption reduction).
- Water saving systems and treatment and wastewater reuse.
- Awareness campaigns on responsible consumption of light and water.
- Managing and minimizing waste in maintenance activities.
- Environmental Management Systems.
- Contracting systems that assess aspects of CSR.

It is important to highlight that sustainable tourism is not only about the preservation of the environment but also the preservation and conservation of cultural heritage (Sancho 1998; Mondéjar-Jiménez et al. 2009). In this sense, FGC continues a refurbishing process of the sanctuary.

Following the environmental policy and the premises established in Vall de Núria's ISO 14001 certification, building refurbish has been designed with a set of technical solutions to maximize energy efficiency rating (type A) which ensures energy efficiency in all facilities. The use of low enthalpy geothermal energy represents a saving in CO_2 emissions and a consumption reduction between 60 and 70% compared to diesel-based systems.

Actions carried out by FGC between 2007 and 2009 in energy efficiency have led to an overall saving of 2.2 GWh/year, which represent 895 t less of CO_2 issued to the atmosphere (see Fig. 4).

Actions have been taken to limit the visual and landscape impact generated by the wiring, poles and electricity pylons through the buried of supply lines that ensure greater security in electricity supply and less impact on valley's wildlife.

These actions were accompanied by the recovery of old sections, bridges, fountains, viewpoints, caves and shelters that provide added value to the environment for hiking. To enhance the tourist attraction of this route a guide with different itineraries has been made, identifying the most important environmental and landscape viewpoints. Moreover, the installation of photovoltaic panels to generate energy has projected.

Other heritage conservation actions are focused on improving the interior spaces for permanent or temporary exhibitions. The progressive surge in skiing demand requires continuous improvement of the facilities (accessibility or security among others) and the winter leisure supply diversification (as Snow Park or Snowshoe circuit) with the challenge of keeping the environmental respect.

Vall de Nuria access by train rack itself represents a travel experience (Ruiz 2003), but FGC has enhanced that experience with the creation of a historic trip as a resource valorization activity (Molina and Cánoves 2010).

Various initiatives have been aimed at quantifying the direct and indirect emissions of greenhouse gases resulting from fuel combustion and electric power to evaluate opportunities to reduce consumptions and therefore emissions. Other initiatives promote train as an alternative mean of conveyance to passengers or goods road transport. In this line, FGC has undertaken various promotional campaigns which outline the advantages of using the train as transportation and how it promotes gases emissions reduction.

Other actions are also representative of the awareness and effort done, such as the implementation of energy saving systems, the incorporation of energy saving systems based on energy-saving lamps and/or detectors presence in facilities refurbishment or maintenance installation criteria.

FGC has taken actions that aimed both reducing water consumption and water reuse. Water is a natural resource whose management is especially important in mountain resorts due mainly to the production of artificial snow.

In this sense, daily control of water at lakes volume, the aquifers level and the use of water and its quality are also necessary elements to prevent any environmental impact and an indicator of concern for sustainable development.

In mountain resorts various actions to improve water management can also be performed, such as: sanitary use water saving, windbreaks installation to collect snow or efficiency improvement in snow cannons, among others.

Waste management generated by tourism and transport activities are carried out by different authorized agents. However, it is necessary a waste separation for proper treatment.

Within the environmental management systems framework (ISO 14001), targets related to waste management and minimization are set. Thus, various actions as the incorporation of containers for selective collection of paper, plastic and organic waste that favour waste recycling have been implemented.

6 Conclusions

For tourism and transport development it is necessary to preserve the environment. Constant actions such as reforestation, forest and aquifers clearing and the recovery of roads (Solá 2006) made in *Vall de Núria* help to ensure environmental sustainability in the long term. Environmental Management Systems implementation and certification is a well known incremental organizational eco-innovation tool (Segarra-Oña et al. 2011b).

The implementation of these systems in mountain resorts is a pioneering feat in the region, being in rack trains a milestone in Europe. *Vall de Núria* is the first integrated service centre in Europe (rack railway and mountain resort) that has achieved ISO 14001 certification. Fuel energy saving has been carried out among the output actions from the Environmental and Quality Management System.

Environmental information and awareness is a key to protect the environment (Sixto and Santiso 2009). In this sense, the spread of environmental respect and preservation values among visitors is a key action for sustainable development of tourism (Jiménez 2009) in the valley. The facilities and activities of this tourist destination are intended to facilitate environmental knowledge and its elements.

Educational workshops that take place as "The Learning Train" collaborate in the dissemination of environmental values and in the awareness of different cultural and technical aspects. In addition, agreements to bring ski and mountain to schools will promote sports tourism.

Interaction with other railway companies through the "Declaration of the railways for Sustainability" (2006) allows the knowledge exchange of environmental management and energy efficiency.

From the tourist management standpoint, the implementation of cooperation agreements through joint ventures or service outsourcing, enable business model increase and management optimization. Maintaining this open business model allows *Vall de Núria* to offer every year new entertainment services that increase the tourist experience value.

In the effort to reduce consumption, an electronic management model with customers and suppliers has been implemented to facilitate administrative procedures and at the same time allows a "paperless office".

Moreover, the implementation of a prevention, environment and quality integrated system is now a fact, as well as specialized agencies and research centres collaboration allows the development of proposals for energy saving measures better targeted and more efficient such as the Catalan Energy Institute (ICAEN) collaboration.

In the tourism promotion area and also the advertisements made in the railway stations, the promotion of own products with area tour operators, the cross-marketing done of various activities and the electronic marketing, revealed to be appropriate actions to ensure medium-term growth.

The enhancement of facilities, services and leisure, culture and sports activities, the enhancement access of rail access to the valley and the intermodal improvement done with parking areas construction at the stations are steps needed to consolidate the Valley's tourist model and its viability in the long run.

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A Proposal of a Business Model in the European Passengers Railway Sector to Reduce its Environmental Impact

María de-Miguel-Molina, Kasper-Vilstrup Roldsgaard, María-del-Val Segarra-Oña and Blanca de-Miguel-Molina

Abstract Business models have received gradually growing attention from scholars and practitioners over the past 10 years but the railway sector has been almost non-existent in the conversation about business models. The innovation of business models could not only enable the European railway companies to improve their quality of passengers' services but also to minimize the environmental impact of operations. Therefore, from the major findings of a literature review of business models, we analyze the Denmark experience of business model renewal in the passengers' railway sector and its environmental impact. Then, we propose an initial business model for the European railway sector that could have a positive influence in the European members' environment.

Keywords Business models · Railway sector · Digital tickets · Environmental impact

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1 Introduction

Business models have been examined from many different perspectives during the past decade ranging from technological innovation, strategic management, marketing, economics and finance to accounting and organizational studies. Authorships across these disciplines recognize that business models must adapt to an increasingly competitive, complex and rapidly changing environment (Wirtz et al. 2010; Sosna et al. 2010; Teece 2010). However, the railway sector has been close to non-existent in the literature on business models.

On the other hand, special attention should be given to the transport sector and measure to reduce CO_2 emissions (Ventosa 2009). According to the European Environment Agency (2011), "specific CO_2 emissions of air transport, although decreasing, are of the same order of magnitude as for road, while rail and maritime shipping remain the most energy efficient modes of passenger transport". Moreover, the train offers more possibilities of transferring many people together than shipping, which is geographically more limited.

Then our research question is: it could be possible improve environment protection at the passengers' railway sector by applying the business models theory? To achieve this goal, in this study we start by describing the key findings from a literature review on business models. In general, the evolution of the European railway sector focuses on sustainability policies so, by means of an initial analysis, we provide an overview of the transformation of the Danish railway sector through the renewal of its business model. We finish by presenting a preliminary proposed proactive vision for railway companies.

2 Literature Review of Business Models

Theories about business models date back to Peter Drucker (1954) who argued that a "good" business model had to fulfil at least two major features: (1) the ability to create products and services for which customers are willing to pay a price, and (2) the ability to develop mechanisms to deliver and capture value. The term "business model" has been part of academic jargon for a long time, but it remained underestimated as a subject for research (Teece 2010) until 10 years ago when it began to be studied after the Dotcom Bubble burst in 2001.

The financial crisis in 2008 multiplied the amount of studies on business models, while the volatility of the global stock markets in 2011 has reinforced the interest for studying business models and their evolution. A Google search confirms this claim: Googling "Business Model" got ca. 100,000 results in May 2000 and exploded from ca. 18,000,000 results in May 2011 to ca. 28,000,000 results in August 2011.

Doz and Kosonen (2010) conducted a study of Nokia Corporation and concluded that it had to adapt its business model more quickly, more frequently and more ambitiously than in the past. Kristensen (2010) studied the attention deficit problem and concluded that we have reached a point of transition where it has become increasingly difficult to capture the daily attention of customers—and for many people the problem is not lack of information but rather information overload.

The dual challenge of adapting business models at a faster speed and getting people's attention can be approached by taking the "right" decisions to develop sustainable business models which benefit not only the single company and its end-customers but also entire supply chains and the society. Porter and Kramer (2011) explain: "Not all profits are equal. Profits involving a social purpose represent a higher form of capitalism—one that will enable society to progress more quickly and companies to grow even more. The result is a positive cycle of company and community prosperity, which leads to profits that endure."

Amit and Zott (2001) define a business model as "the structure, content and governance of transactions" between a company and its stakeholders, while Magretta (2002) explains that testing assumptions about business models is the "managerial equivalent of scientific method [where] you start with a hypothesis, which you then test in action and revise when necessary"—reminding us that a business model is very likely to fail when it builds on faulty assumptions about how the company delivers value to its customers.

Afuah (2004) defines a business model simply as "a framework for making money", which is the basic description that is frequently used to describe the performance of business models. Yet, the good stories behind the organizational development may be perceived as the "real meat" of the business models (Itami and Hishino 2010).

Teece (2010) concludes that a business model is the "management's hypothesis about what customers want, how they want it, and how the enterprise can organize to best meet those needs, get paid for doing so, and make a profit". This definition supports Drucker's ideas about a "good" business model, which recognizes the transformation and renew of business models as a recurrent management challenge.

Baden-Fuller and Morgan (2010) determine that business models play a central role in progressing management thinking: and likewise Giesen et al. (2010) claim that innovation of business models is the fundamental part of an organization since their design has become decisive for success. To gain perspective, Doz and Kosonen (2010) outline a leadership agenda for accelerating the renewal of business models in the belief that many companies fail not because they do something wrong, but because they keep doing what used to be right thing for too long—and thus suffer from the rigidity of their own business models.

Sosna et al. (2010) reminds us that even mistakes can be very useful in helping firms to learn from the most demanding environments, while Williamson (2010) warns that continuous change in global demand patterns challenges companies to learn how to combine costs and innovation to compete in the global economy. To meet this challenge, companies need to know about their customers' requirements at all times (Teece 2010).

To sum up, business models encompasses profound modifications in an organization that not only changes or innovates the way it delivers value to its customers (Lovelock and Wirtz 2011), but also builds risk into the business model and transforms the supply chain (Girotra and Netessine 2011).

3 The Sustainability of the European Railway Sector

The railway sector has transformed remarkably over the past 30 years and it deserves a level of attention much more in line with its important role in the modern society—and it is currently undergoing a novel era of change that is too important to ignore. The transformation of the railway sector is critical for our economy because it is responsible for the environmental impact of the billions of daily travels with direct impacts of CO_2 emissions, infrastructure and material consumption—and with indirectly impact on the environmental suggested by Dlamini (2011).

Over the past decades, the European railway sector has changed from in most cases a public monopoly model to other types of mixed models in which public and private management go hand-in-hand in service and product delivery. Although the timeframe for this evolution has not been the same in all European countries, as some started their reforms over 20 years ago, while others, mainly eastern European countries, have planned to begin (Drew and Ludewig 2011).

The European Commission have been rethinking the issue of mobility and transport in urban and metropolitan areas. It emphasizes the importance of integrating land and transport, cutting down on pollutants emitted by transport, increasing management systems and reducing the construction of large infrastructures and introducing systems to enable external stakeholders to engage in planning activities (Miralles-Guasch et al. 2010). This means that upgrading existing infrastructures entails major environmental savings compared to building new ones. With Transport 2050 (European Commission 2011a), the European Commission has adopted a roadmap of 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment. At the same time, the proposals will dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050.

The sustainability of the railway sector has also been criticized; for example O'Toole (2008) claims that some railway lines use more energy per passenger per km: and that too few passengers generate more greenhouse gases than cars and buses. The railway sector recognizes that it has to compete with other means of transport based on its sustainability, efficiency and safety (Cer 2010), while it remains clear that the railway sector becomes more competitive from collaboration (Givoni and Banister 2007); for example by increasing dynamic mobility (Sauter-Servaes and Nash 2009).

4 Study of the Transformation of the Danish Railway Sector

4.1 Evolution of the Danish Railway Sector and Its Environmental Commitment

The Danish railway company has a long tradition as one of Northern Europe's leading companies in terms of CSR and sustainability strategies which root back to the 1980s (DSB 2011a). In fact, DSB is the first company in Denmark to publish a green accounting strategy. In 1992 DSB publishes its first official environmental policy after some years of experiment and practice. In 1995 it publishes a detailed plan with a specific action plan, among others, reducing energy consumption gradually including analysis of options for fitting catalytic converters to diesel locomotives (DSB 2011b).

In 1997 the deregulation of the railway monopoly divides it into two separate organizations (1) Banedanmark in charge of the rail infrastructure and (2) DSB in charge of rail services. In 2003 DSB starts its first international operations in Sweden which subsequently enables it to increase revenues year-by-year (DSB 2011a).

In 2006, DSB signs a Curve Breaker Agreement with the Centre for Energy to save a total of 10% of electricity consumption for train operations and related activities per passenger km in the period 2006–2010 (DSB 2011e). In 2008 DSB reformulates a new sustainability strategy (DSB 2011c). The new sustainability strategy is labelled "Project Change Track" and it introduces broad ranges of changes from a new travel slogan "Travel with thoughtfulness" to encourage customers to assume co-responsibility, installation of energy saving light balls in the train stations, "GreenSpeed" education for the train conductors to optimize the energy consumption of train operations and electricity reduction in office buildings (DSB 2009).

The redesigned sustainability strategy is manifested in the entirely green corporate logo. The sustainability goals are extremely ambitious and embedded in the Danish Transport Ministry's plan for "Growing Railway" (2009). The reinforced sustainability strategy introduces a range of new standards for the European railway sector, e.g. compared to 2005 double the number of passengers in 2020, lower the energy consumption per passenger km by 20% in 2020, lower the climate impact by 50% in 2020 and be CO_2 neutral in 2030 (DSB 2010). DSB increased its operations both nationally and internationally. The number of passengers rose for the Danish railway mainly due to international operations (see Fig. 1).

In 2008 DSB wins the International Union of Railways (UIC) Sustainability Award which is the first time that the organization gives an award to projects which have helped to make the railway sector more environmentally friendly and sustainable (DSB 2009). In 2010 DSB signs the UIC Declaration on Sustainable Mobility and transport which is an interpretation of United Nations Global Compact. The declaration supports UIC's work to raise awareness about the train as a sustainable mode of transport.

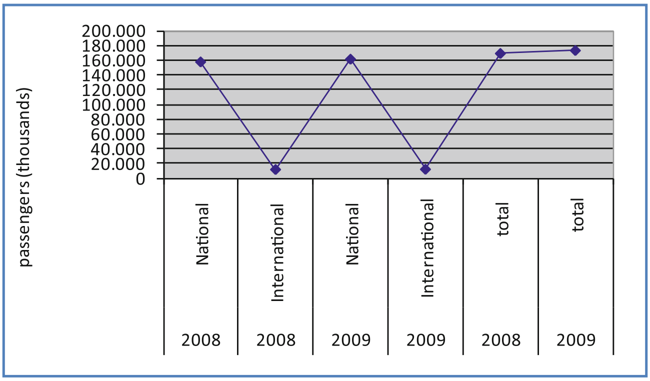

Fig. 1 Passengers carried by rail Denmark 2008–2009. *Source* authors' own based on Eurostat (2011)

In 2011 DSB redefines the environmental and climate strategy—and signs a Climate Partnership with DONG Energy to cut down the energy consumption in the DSB buildings (DSB 2011e).

4.2 Digital Tickets and Related Commercial Offerings that Reduce Paper Tickets and Other Costs

In May 2011 the European Commission regulation allows the harmonization of procedures, data and messages to be exchanged between the computer systems among railway companies, infrastructures and tickets in order to provide reliable information to cross-border passengers and to issue tickets on the European Union railway network in accordance with Regulation 1371/2007 on rail passengers' rights and obligations. According to the European Commission (2011b), there are two elements in telematics applications in the rail sector:

1. Applications for passenger services, including systems providing passengers with information before and during the journey, reservation and payment systems, luggage management and management of connections between trains and with other means of transport;
2. Applications for freight services, including information systems, marshalling and allocation systems, reservation, payment and invoicing systems, management of connections with other means of transport and production of electronic accompanying documents.

A first stage entails a significant reduction in paper use, but the European railway sector goes even further in the process of digitalizing channels and commercial offers. In Denmark, record sales of digital mobile tickets replace the classic paper ticket with spectacular leaps forward. By transferring customers to the digital channel, the Danish railway gradually releases resources from physical points of sale. The commercial efforts pays off on a grand scale when over 55% of the tickets are sold via digital channels in December 2009 (DSB i dag 2011a).

The digitalization of rail transport in Denmark is at relatively more advanced stage, which means that the customer can combine travels from A to B with commercial service offers, e.g. buy services via mobile technology, make seat reservations with the mobile phone, buy car parking tickets with the mobile phone. The digitalization of tickets and related commercial offerings can be divided into four categories (see Table 1). The digitalization of tickets provides more flexibility for the customer and appropriates the busy modern lifestyle where many customers want to be able to buy when they want; anywhere they want—without queuing and other demanding activities.

- The first category "single ticket" can be either a machine ticket printed at the railway station, an internet ticket purchased on the internet or a mobile phone ticket purchased via SMS, mobile app or mobile internet platform. This category follows the conventional travel logic from A to B.
- The second category "voucher ticket" can be either a physical card purchased at the railway station or internet; or a mobile phone ticket purchased via SMS technology. This category is in line with the classic travel logic from A to B.
- The third category "season ticket" can be either a physical card purchased at the station or internet or mobile phone ticket purchased via SMS technology or the internet. The customer pays a monthly flat-rate price to travel unlimited in a defined area or number of zones.
- The forth category "complements" goes beyond classic travelling logic from A to B. The bicycle initiative is an exemplary case of the second-order logic. This category includes all types of product or services from the crowd via apps, mobile internet or SMS-based technology; for example, complements to individual tickets, renewals of payment contracts, reminders, travel information, seat reservations in the trains, car parking tickets, just to mention a few examples. This category recognizes the travel A–B in a context.

In terms of value creation—digital products and services not only deliver to the customer value proposition, but they also help the railway company to cut costs and reduce to environmental sustainability in the supply chain through the reduction of physical tickets. The recently published e-commerce analysis for the second quarter of 2011 shows that digital tickets have pushed DSB website so far forward that it now the most frequently used site in Denmark.

The number of sold mobile tickets surpassed 1 million in 10 months since the SMS ticket (single ticket) was launched in January 2008. In July 2011 the sales of mobile voucher tickets (with 20 zones) tripled the number of mobile voucher tickets to 75.000 compared to the previous month (DSB i dag 2011b).

In summary, digital tickets provide more customer flexibility, eliminate waiting times in queues, and cut down physical materials in big quantity each day and thus contribute to a more sustainable public transport sector.

Table 1 Overview of ticket types and related commercial offerings

Single ticket			Voucher ticket		Season ticket		Complements
One-way or return			Multiple travel ticket		Travel pass		Beyond category
Machine	Internet	Mobile phone	Card	Mobile phone	Card	Mobile phone	N/A
Printed at the railway station	Printed at home on paper or sent as text to the mobile phone	Purchased via SMS, mobile app or mobile internet	Purchased via internet or traditional sales point	Purchased via SMS text	Purchased via internet or traditional sales point	Purchased via SMS text, app or internet	Train services beyond travelling from A to B
Single or return ticket	Single or return ticket	Single or return ticket	Ticket with n-travels	Ticket with n-travels	Ticket with unlimited travels in a defined area or n- zones	Ticket with unlimited travels in a defined area or n-zones	Free, payment or "freemium" models where the customer pays indirectly or additionally to the train ticket
Static ticket can only be returned in the sales point at the station	Static ticket can only be returned in the sales point at the station	Static ticket can only be returned in the sales point at the station	Stationary ticket can be changed in sales point, online or ticket machine	Flexible ticket because the customer can define the n-zones	Stationary ticket can be changed in sales point, online or ticket machine	TBD. (not yet in the market)	Plug-and-play functionality with commercial products and services in offered in real-time
Classic A to B travel logic	Classic A to B travel logic	Classic A to B travel logic	Classic A to B travel logic	Modern A to B travel logic	Travelling in a zone or area	Travelling in a zone or area	A–B in a context

Source authors' own

4.3 Business Model Innovation in the Greater Copenhagen Commuting Systems: "Bring Your Bike"

Combination with other sustainable means of transport has had a positive effect on the development of the Danish railway sector. The chief executive of the Greater Copenhagen Commuting system, Gert Frost, explains the rationale as follows: "Sustainability is a key concept for us. We want to be a sustainable company that delivers sustainable solutions. The train is currently the only means of transport that may reduce or eliminate CO_2 emissions. We can make a difference to the climate, the environment, the society and for future generations." (DSB 2009).

In 2009 DSB experiments with a new "free bike" service where people in the Greater Copenhagen Region can carry their bicycle in the wagon with any valid travel ticket. DSB has a long tradition of combining public transport, e.g. trains with ships, airports, buses, cars, commuting systems, metro lines and bicycles—and it has a long tradition of implementing customer initiatives (DSB 2011b). Indeed bicycles play a major role in meeting transport needs in Denmark (Regeringen 2009).

In 2010 the bicycle service is extended and in 2011 the service is enhanced with a stream of new services to make it easy for people to get around the city; for example, modifying the design of the wagon to create more space for bicycles inside the commuting trains, mount slides on the railway stairs to easily bring the bicycles up/down, improve bicycle parking and install bicycle pumps at selected stations (DSB 2011d). In May 2011 over 600,000 customers carried their bike on the Greater Copenhagen commuter trains compared to fewer than 200,000 in May 2009 before the *free bike* offer came into force.

The gradual innovation of the business model has attracted new customers in the first quarter of 2011 leading to the best passenger numbers in 20 years. Sales director Niklas Marschall concludes that "There is no doubt that it is offers like free bikes which convince more customers to use the commuter trains, and we have experienced an impressive growth in passenger numbers." (Cykelistforbundet 2011).

In summary, the "bring your bike" commercial initiative describes the great potential of combining the travel chain with other means of sustainable transports.

5 Proposal

The railway sector is important for a sustainable economy because the train is capable of transferring many people together at the same time while doing it CO_2-neutrally. Reforms enforced by the European Union in the European railway sector is likely to become significant in the future, but not only reforms challenge the railway companies to renew their business models, rather the customers progressively demand increasingly sophisticated digital products and services which were completely unrealistic 10 years ago.

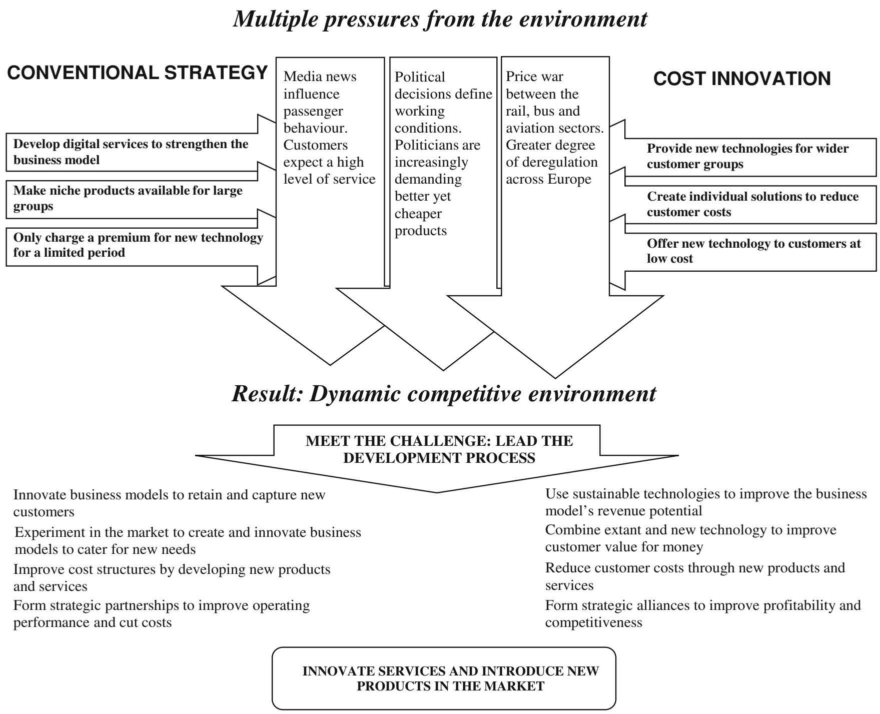

Fig. 2 A proactive vision for railway companies. *Source* authors' own based on Williamson (2010)

Frazier and Ryder (2000) predicted that the future of the railway sector would lay in the continuous transformation of its business model by adding value to its operations to meet the customers' changing needs and requirements. In our successful case study, we have seen how DSB has developed sustainability standards in the Danish railway sector. For many Danish customers it is a remarkable improvement to be able to buy digital services with a few clicks on the mobile phone and the number of digital tickets is increasing. Also the "bring your bike" initiative in the Greater Copenhagen commuting trains is a great example of a complementing service that delivers to the customer value proposition in a unique way.

The advanced customer demands have initiated a fragmentary transformation of the European railway sector and that is why theories about business models can guide railway companies to deal with future challenges. Johnson et al. (2008) critique that everybody speaks about business models but that no one knows what it is—or how to do it, so in Fig. 2 we provide an initial summary of the measures that can be taken to meet the challenge of creating sustainable business models in the railway sector.

Moreover the digital technologies accelerate the renewal of business models in the European passengers' railway sector which is a basis for rethinking the classic travel logic from A to B and to deliver added value to the customers.

6 Limitations and Future Research Directions

Our aim has been to analyze if, from a theoretical point of view, we can connect business models theory with improving environmental protection at the railway sector. As we have studied the Danish experience, it is possible a renewal of the railway companies' business models taking into account the environmental focus. This perspective can be positive for customers' satisfaction as well for environmental protection. The major limitation of this study is that we have considered only one case study (Denmark) and in the future we should increase the number of them.

At this first analysis we propose a preliminary model that we should test and improve in the future if used, to show the connection between business models and environmental protection. This model could also help railway companies to face the new challenges that promote the White Paper Transport 2050 (European Commission 2011a). Through this model we encourage managers to continue the development of digital channels along with commercial initiatives to develop the market, while we persuade our fellow scholars to study the renewal and transformation of business models in the European railway sector in the forthcoming years.

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Challenges in Last-Mile e-Grocery Urban Distribution: Have New B2C Trends a Positive Impact on the Environment?

Jesús González-Feliu, Bruno Durand and Dina Andriankaja

Abstract The business to consumer distribution services (B2C), mainly related to e-commerce, know nowadays a real boom that is sometimes accompanied by fractures. To better understand this fast-changing situation and support researchers and practitioners, this chapter proposes a scenario assessment analysis focused on the new B2C strategy trends and the joint co-ordination of e-commerce stakeholders to better optimize consumer's delivery flows. First, the two main logistics solutions adopted by online retailers are introduced. Second, the main customer's delivery services in France are presented. The proposed scenarios take into account the relations between urban development and B2C logistics schemes. Finally, the scenario assessment method is introduced then environmental impacts are estimated and analyzed each scenario.

Keywords e-Commerce · B2C logistics · End-consumer delivery strategies · Environmental impact

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1 Introduction

After a slow start, particularly in France, e-commerce services know nowadays a real boom that is sometimes accompanied by fractures, especially those related to the distribution of the purchased products. For this reason it seems to be urgent to worry about business to consumer (B2C) transport flows. These flows are in general deliveries from a commercial activity, a warehouse or a depot to a location near the consumption place, either at home or on proximity reception points. In this context, city logistics can be a key factor in online selling development success or failure. In the last decades, city logistics has been developed to deal with the main problems of urban freight distribution, studying freight movements in urban areas and proposing solutions to reduce congestion and pollution.

This chapter aims to study the impacts of both retail urbanistics policy and e-grocery development on household shopping trip behavior, examining the relations between e-grocery end-consumer flows and city logistics systems. First, the two main logistics solutions adopted by online retailers are described, focusing on both inventorying strategies (order picking) and end-consumer supply schemes (freight transport and shopping trips). Then, four current French logistics models are introduced. Finally, the asses-sent and further analysis of 6 scenarios is proposed. The four first scenarios derive from the generalization of each proposed logistics model. The other two scenarios mix these four models, one following current trends and the other taking into account the relations between urban development (and so household locations) and e-grocery B2C services. The scenarios are then simulated and compared to a real reference situation (the urban area of Lyon in 2006). As a conclusion, the main practical implications of these scenarios are proposed.

2 The Logistics of e-Commerce

Logistics plays a major role in e-commerce success, yet its status remains secondary (Durand and Gonzalez-Feliu 2011). Indeed, when an online store receives and sends its order under the expected conditions, the customer has no reason to complain, but when the deliveries present some nuisances (delays, thefts or losses, among others); it has direct consequences on the continuation of purchases on the frequented website (Durand 2010). Moreover, B2C services need specific logistics that, in particular, depend on the products sold (Baglin et al. 2005). According to Durand et al. (2010), there are almost as many e-logistics as families of products. Moreover, the choice of each store's logistics schemes is guided by both the nature of products and the type of retailer. Indeed, a storekeeper, only present on-line will not choose the same options as a colleague who also sells in-store. Concerning these logistics schemes, they are composed of two main components: inventory strategies and transport schemes (Durand and Gonzalez-Feliu 2011).

2.1 Inventory Strategies in e-Commerce Distribution

According to Dornier and Fender (2001), logistics is an essential component of web-based[1] retailers' strategies. Inventory strategies for e-retailers are directly related to online order-picking (Paché 2008). Two basic organizational models can be defined: order-picking at a dedicated site and store-picking. According to De Koster (2002), when the number of stock keeping units for B2C is large (several tens of thousands) and the e-commerce part of the business is not marginal (several hundreds of orders a day), storage on a specific site, dedicated to e-commerce, seems a necessity. Three alternative inventory schemes have been considered:

- *Upstream storage*, in producers' warehouses for slow moving items. In this organizational model, the facilities and the inventory management are in general followed by the producer itself and the distributor takes the role of a customer in the inventory management chain,
- *Storage at distributor's platforms*, for fast moving products, in national or regional facilities belonging to the distribution operator or its subcontractors and exclusively dedicated to e-commerce. These inventory schemes can be managed by the distributor itself of a specific logistics providers,
- *Downstream storage*, for very fast moving articles in urban (or suburban) depots, directly connected to on-line sales structures and managed by distribution companies.

Order-picking in producers' warehouses, contains several variants (Durand 2010). In this chapter the variant that minimizes the number of home deliveries (cf. Fig. 1) is presented to examine its process. First, on-line consumers purchase products on a retail website, making a group of orders. Then, the website follows the information about these orders to the concerned producers. The latter carry out order-picking for its corresponding products, sharing the transportation operations on the same logistics provider to avoid multiple deliveries. Once assembled, orders soon start to be delivered to Internet users. The fact that each household receives one delivery vehicle makes this option the most economic and environmental-friendly variant.

This alternative is extremely developed in the editorial supply chain, because of a plethoric offer of several million on-line articles, but it is almost absent in the e-grocery sector (Durand 2009). Indeed, the offer of cyber-markets is only composed of approximately five or six thousand very fast moving articles. Consequently, grocery items are rather stored downstream in warehouses (or depots), allocated to distributors. It corresponds to the two other order-picking alternatives. According to Yrjölä (2003), a logistics unit dedicated to e-grocery operations justifies itself since the number of on-line consumers per km^2 is increased. Regional warehouses are in general used by big e-grocery groups, like Carrefour and Auchan (TL&Associés and LET 2009), whose volumes and strategic axes justify the

[1] Also called e-tailers (Durand and Gonzalez-Feliu 2011).

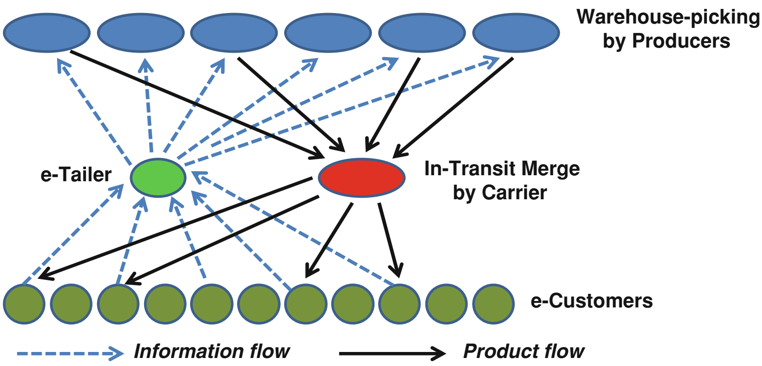

Fig. 1 Upstream warehouse-picking and in-transit merge operations (adapted from Chopra and Meindl 2004)

investments that suppose to implement a network of national and/or regional e-commerce logistics platforms. On the other hand, smaller groups can also choose order-picking on a dedicated site, but are in general urban or peri-urban platforms a big store or a local platform, not only dedicated to e-commerce but also to traditional distribution. Finally, urban depots are also used in France by big groups in some big cities (Paris, Nantes) for proximity deliveries (Durand and Vlad 2011).

Concerning last mile deliveries, several variants can also be observed: the management of home deliveries being integrated in or given to a subcontractor, although mixed logistics systems are also found in practice.

On-line retailers, who choose to lean on a network of existing stores, prefer a simpler and quicker operational process. This model is based on the fact that on-line orders are transferred to the store nearest to the e-consumer's location. Order-picking is often made by employees of the concerned store and, once commands are prepared, home deliveries are made by the storekeeper or by a logistics provider. In this way, store-picking strategies suppose reduced investments and, therefore, a very short return on investment. Another asset of this model is in the fact that on-line consumers can opt to pick-up goods purchased, directly in store (as shown in Fig. 2), avoiding transportation costs in this way. However, this second model contains a risk: that of the disturbance of traditional in-store customers by pickers. Faced with this eventuality which could entail leaks of consumers, Ogawara et al. (2003) suggest adopting warehouse-picking as soon as the customer catchment area has good potential. In any case, the store-picking model constitutes the proof that on-line business does not mean the death of outlets: indeed, their mobilization could be an invaluable support to e-logistics.

The existence of an urban specific segment of a transport chain for the first and last kilometer is one of the main particularities of the mobility of goods in major cities. This urban segment has an own characteristics as the passage through a terminal means in most cases a transformation of the forms of mobility: the first and last kilometre, those of the final distribution or initial, carried out with

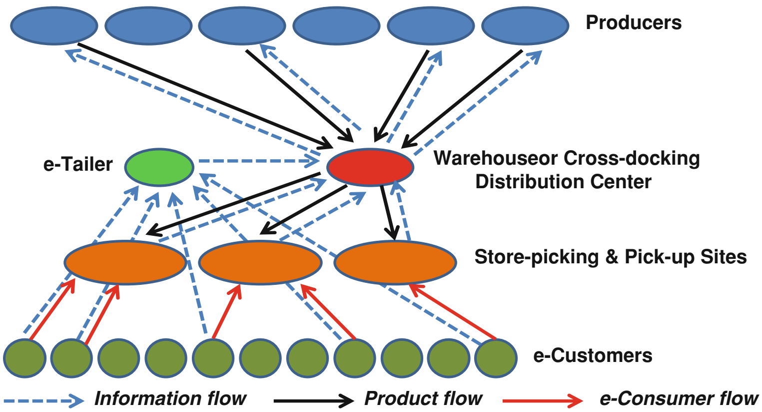

Fig. 2 Downstream store-picking and e-consumers pick-up operations (adapted from Chopra and Meindl 2004)

different vehicles (generally smaller, often older and pollutants), and often with different operators (with a predominance of small subcontractors) and the rest of the transport chain.

One of the main characteristics of freight transport in major cities compared to smaller cities is the very common passage of goods through a terminal during their transport. Thus, before being delivered in an urban area (or sent from this urban area), a product has every chance of passing through a logistics terminal (a cross-docking terminal), in other words, a nodal point at which the goods will be at least transferred from one vehicle to another, and often will undergo some operations (storage, packaging).

It is the same for the delivery of goods ordered online. These goods are prepared at a logistics terminal before their final delivery to the customers (households). Changes in the location of these terminals will directly affect the distances and routes used by vehicles to deliver urban areas.

Increasingly common in large urban areas, the logistics facilities should find welcoming places. Two logic reasoning patterns are at work in the spatial arrangement of logistical equipment. There is a significant part in developing large multi-specialty areas and logistics facilities in a coherent architectural and managerial set. “Powerful logistics nodes” (Savy and Liu 2009) where are installed one or several logistics areas, appropriate the economic landscape of the Paris region. In addition, many logistics terminals disperse over a large part of metropolitan France. Last thirty years, logistics terminals have been developed in areas located over 30 km of urban centres (Mykolenko 2003). Dablanc and Rakotonarivo (2010) have demonstrated this logistics sprawl by using the case of parcel service terminals in the Paris region.

If logistics terminals have moved away from dense cities, the population remains concentrated in the city center. Logistics sprawl of terminals has an influence on the increasing distances to travel to deserve the urban population that is to say about the environmental impacts of urban delivery, like the delivery of e-commerce.

Deliveries of e-commerce are mainly characterized by deliveries to individuals. The major difficulty of these deliveries is the absence of the consignee. This requires transport operators to pass a second or a third time and creates a disorder in their organization and a waste of time. A waste of time involves additional costs. The delivery of last mile is therefore one of the obstacles to the development of the delivery of e-commerce. This is why the establishment of pick-up points is one possible solution to these high costs of urban distribution (Augereau et al. 2009).

2.2 Transport Strategies and Final Distribution

In the last decades urban freight distribution became an important research subject, to answer to a more congested and polluted urban context (Dablanc 2007). Recent studies have defined and characterized the different movements of urban goods (Ambrosini and Routhier 2004; Ségalou et al. 2004; Patier et al. 2007; Gonzalez-Feliu et al. 2010a; Russo and Comi 2011). Urban goods movements present several categories. Two of them are predominant and represent about 90% of the overall urban goods movements (Gonzalez-Feliu et al. 2010a): *inter-establishment supply movements*, which are related to freight distribution between the different activities, and *end-consumer commodity movements*, where the purchased goods are moved by the consumer, related to shopping trips. The remaining 10% contains the city maintenance and construction logistics movements, the waste distribution and a number of small particular activities such as postal services, among others.

Inter-establishment supply movements deal with the last mile of the supply chains. They are studied in-depth in both supply chain management and city logistics research and represents between 35 and 45% of the total road occupancy derived from urban goods movement. End-consumer movements represent about 45–50% but have been less studied since they are assimilated to shopping trips, so to personal trips and not to goods flows. Although nowadays most of these flows are tradition shopping trips, B2C flows start to take a non-negligible part, as they currently represent about 5% of total shopping trips and could represent, more than 15% in 2020 (Georget et al. 2008). In this context, three main strategies are commonly seen in practice:

- *Shopping drive services*, mostly related to peripheral stores and made popular in France by the Auchan group, where customers purchase online and choose the pickup store. Then, they make a car trip to the chosen store where they take their command without waiting queues. Based on the considerations stated by Gonzalez-Feliu et al. (2012), two main trips can be associated to shopping drive: household-shopping trips, which imply big distances in central households, and work-shopping-household trips, which suppose a few increase of the usual work-household travelled distance (in Lyon,[2] the average increase distance is of 3 km per trip, with respect to the 24 km of a household-shopping-household trip associated to a drive service),

- *Home deliveries* that are related to the order-picking strategies defined above. Note that distances of warehouse-based home delivery routes are about 200 km and involve about 40–50 households (Durand and Vlad 2011), whereas store-based home deliveries involve 10–12 households for an average distance of 50 km (Alligier 2007),
- *Proximity reception points networks*, where the supply changes consist of including local depots (Augereau and Dablanc 2008) or using small supermarkets as reception points. In this case, the ordered products are directly prepared in a depot, located in a peripheral area. Then, the command is delivered to a proximity reception point in which they are picked up by the final consumer (Augereau et al. 2009).

2.3 Logistics Practices Observed by French e-Grocery Distributors

This subsection provides a synthetic overview of e-grocery development in France. If on-line sales concern almost all business sectors, one has to admit that e-grocery still represents a niche market: its turnover was only, about 1.2 billion euros in 2009 in France. Besides this, currently only about three million French Internet users use on-line supermarkets. This type of sale is attractive firstly for reasons of practicality and of time saving. Consumers want to save time during food purchasing in two ways: (1) on going to the store by reducing (or even by eliminating) their round trip time and, also, the time of spent looking for a parking space; (2) during their time in store by eliminating waiting times at food preparation counters and at the checkout. Internet users underline the practicality of on-line sales, also in two ways: (1) on-line stores are continuously open, 24 h a day—therefore this scenario allows transactions at any time of the day; (2) on-line orders can be directly delivered or dropped off at pick-up points. Let us add that the consideration of environmental problems also seems to push households to develop their Internet purchases: the environmental impact seems rather positive because of the reduction of movements and of GHG.

The cost of this service seems to constitute the major obstacle to e-grocery development because, in the mind of many French people, on-line shopping is more expensive: either the price of products sold on Internet is higher because it integrates the cost of basket picking and delivery costs; either the price of articles is situated at the same level as that practiced in store and it is advisable to add to

[2] Statistics from the National Household Personal Trip Survey of the Lyon urban area (Sytral 2006).

this the logistic service costs. Less sensitive to this cost than the other SPC (Socio-Professional Category), the SPC+ (upper SCP) is also, at the moment, the category the most attracted by e-grocery: more half of their food expenses would already be made in cyber-markets, while the offer, a real element of differentiation between e-grocers, is particularly reduced with only 7,000 references on average, compared to 40,000 for a traditional supermarket. Finally, to present the main French logistics practices in e-grocery distributors, four main actors have been selected: Auchan, Carrefour, Casino and Intermarché. The simulations will then be based on their distribution strategies and logistics models.

- *The Auchandirect logistics model*. *Auchan* is one of the first large French retailers to have invested in the e-grocery market by launching *Auchandirect* in 2001. At this time, the customer catchment area, served by the central warehouse of Chilly-Mazarin (near Paris), was limited to the southern region of Paris. Since then, whilst sticking with warehouse-picking, *Auchandirect* has widened its national coverage by opening five new sites: a second in Ile-de-France and four near major cities (Lyon, Lille, Toulouse and Marseille).
- *The Ooshop distribution schema*. *Ooshop* is the e-grocery division of *Carrefour* in France. *Carrefour* is one of the most important grocery distribution groups in the world and the first in Europe. Because of its big size and the spread spatial distribution of its platforms, *Carrefour* has decided to create a separate company, *Ooshop*, which manages online sells. Non fresh products are stored and managed on a national e-commerce platform, from what they are distributed into local platforms, which are not only used to e-grocery but have a specific section to this business field. These platforms are in general located near gross markets in big urban areas. Then, a specific logistics provider, Star's Service, specialized on home deliveries, collects the commands and completes them with fresh products from the local gross market. Then, home delivery routes are made to deliver customers. This system needs the customer to command at least with 1–2 day anticipation in order to ensure the entire logistics process.
- *The Cdiscount system*. Analogously to *Ooshop* and *Carrefour*, Cdiscount is the e-grocery division of *Casino* group in France. *Casino* is smaller than *Carrefour* but presents a much expanded network of proximity supermarkets: the *Petit Casino* network (traditional small supermarkets) and the *Spar* and *Vival* networks (proximity stores that are open until 9–11 p.m., the closest to the 7/11 group that can be found in France). This structure allows the *Casino* group to propose a reception point e-commerce service, which works as follows. Commands are prepared on a regional platform, and then they are delivered to the chosen reception point. The customer can pick-up his or her command at any hour (respecting of course the store's opening hours). Because the density of these networks is high in big cities, this schema can be competitive if its usage rate increases in the next years.
- *The Expressmarché logistics model (Intermarché)*. Pick-up directly in store, an alternative to store-picking, seems to have convinced the most hesitant French distribution brands. It is in particular the case of Intermarché, whose will is to

control its logistic costs (the main reason behind this choice). It is, therefore, on 300 supermarkets that *Expressmarché*, the cyber-market of the grouping, leans today. *Intermarché* has chosen to take advantage of the density of its network (a selling point every 18 km). If HD can also be envisaged because of this very good territorial cover, *Expressmarché* was also made available on its two pick-up alternatives: the classic in store pick-up and the drive-through, which means that Internet users do not need to alight from their vehicles.

3 Impacts of B2C Trends on e-Commerce: A Scenario Assessment Approach

In this section, an assessment of several distribution scenarios related to e-grocery development, based on the four models described above is presented. In order to isolate the effects of e-commerce from other effects, such as population growth or changes in retailing demography, the scenarios are built from a reference by changing only the organizational schemas of B2C distribution (with the respective changes in the overall supply chain if applicable). For each hypothesis, a quota of 15% of e-commerce users is supposed, in order to simulate a near future situation, according to Georget et al. (2007).

In order to define a reference situation authors have selected a significant urban area where statistical results concerning population, establishment and shopping trip trends are available. More precisely, the urban area of Lyon is chosen. This city and its surroundings represent the second metropolitan area in France, for which recent data is available (2005–2006). This area represents about 2,000,000 inhabitants and 800,000 households. The main data sources are an extract of the register file of companies (SIRENE file) of the chosen area, the corresponding census database (INSEE file), and the 2006 personal trip survey, which follows a French standard (Sytral 2006).

The proposed scenarios can be grouped in two sets. The first set (S1-i) contains four single scenarios each of them derived from the generalization of a sole logistics model. Then, a second set (S2-i) of scenarios results from the combination of these four logistics models in two different combinations: the first corresponds to current practices, and the second to a more systemic approach where each zone privileges the distribution channel that meets better its needs, including in terms of environmental and social impacts (Routhier et al. 2009). In any case, the usage rate of e-commerce is set to 15%, taking into account Georget et al.'s (2007) considerations. Concerning the distribution of shopping practices, the assumption that e-grocery user profiles are the same that traditional shopping is made. Indeed, the categories of e-commerce shoppers proposed by Rohm and Swaminathan (2004) are similar to those of French households for traditional shopping (Van de Walle and Rivoire 2005). This assumption will be able to define the usage rates of each distribution channel. The four single scenarios are defined as follows:

- S1-1: An "**Expressmarché model**" scenario based on the assumption that all households asking for e-commerce services are served by a store within their urban area. This scenario supposes two types of retailing activities: small retailers will cover small routes from all locations within the urban area, whereas big stores will use peripheral stores as the starting point of longer routes. Two types of services are proposed: store-picking services and home deliveries. Concerning store-picking, household behavior is assumed to be similar to that of traditional shopping. Regarding home delivery routes, they are supposed to be similar of those defined by Alligier (2007) from specific surveys (vehicles of an average total weight of 2.5 that deliver 10 households making a distance of near 50 km). In this scenario, all retailers are supposed to offer B2C services.
- S1-2: An "**Auchan direct**" scenario. This hypothesis supposes that only home deliveries are allowed, following a warehouse-picking schema. This supposes the use of a regional depot (about 50 km from the city center), with the changes that this structure suppose on the global supply chain. Indeed, the quota of e-grocery is subtracted to traditional supply flows and affected to these regional depots. Then, light goods vehicles (3.5T) are used to deliver an average of 50 households per route (Durand and Vlad 2011). The total traveled distance is in average 200 km per route. This scenario supposes that only large e-grocery groups are proposing these services.
- S1-3: An "**Ooshop**" scenario. This scenario is similar to S1-2 but differs in the location. Local platforms are located in far peripheral areas (about 20 km from the city center), then, light goods vehicles (3.5T of total weigh) make home delivery routes each of them servicing about 25 households and travelling about 120 km (TL&Associés and LET 2009).
- S1-4: A "**Cdiscount**" scenario. This scenario supposes a high network of reception points supported by peripheral platforms. Goods are transported from the corresponding platform to assigned reception points from the same regional platforms that traditional retailing supply, but using a specific fleet of small trucks (about 7T of total weight). Then, customers pickup the purchased products on food or by car, making very small trips in both cases. The shopping trip behaviour of households picking up the purchased products at proximity reception points is supposed to be the same as traditional shopping at proximity small supermarkets (Van de Walle and Rivoire 2005).

The two combined scenarios derive from the combination of S1-1 to S1-4 and can be defined as follows:

- S2-1: **A business as usual situation**. In this scenario, an e-grocery usage rate of 15% is assumed, with a distribution that follows current trends. To do this, a current model is associated to each concerned store, i.e. for each grocery retailer located in each zone of the concerned urban area, an e-grocery model is assigned. Very small retailers or stores that manifested not to be proposing these services are supposed to not propose e-grocery alternatives in the current simulation. The distribution rates are fixed as follows: 10% *Expressmarché*, 30%

Auchandirect, 40% *Ooshop*, and 20% *Cdiscount*. Concerning the geographical distribution of these services, *Cdiscount* is spread in all the area, but more concentrated in town centers, whereas *Auchandirect* and *Ooshop* serve all the zones. *Expressmarché* is more developed in the near periphery (the close surroundings of the main city).

- S2-2: A second mixed scenario that takes into account **best practices** for each channel and finds the synergies between these channels. This is a hypothetical situation that however is applied under realistic conditions: the enterprises are in competition, and no collaborative strategies between competitors are envisaged. Only internal collaboration to optimize each enterprise's resources is considered. The distribution rates are fixed as follows: 10% *Expressmarché*, 25% *Auchandirect*, 25% *Ooshop*, and 40% *Cdiscount*. Moreover, the geographical distribution of these services is made to decrease the traveled distances of B2C flows and shopping trips. More precisely, *Expressmarché* and *Cdiscount* are more developed in the main city and its close surroundings (35–40% of the total population) whereas *Auchandirect* and *Ooshop* serve the peripheral zones.

In order to simulate these scenarios, authors adapted the simulation procedure proposed by Gonzalez-Feliu et al. (2012), which chart is shown in Fig. 3. Three existing tools are used to obtain the basic inter-establishment movements and traditional purchasing flows. Through FRETURB model (Routhier and Toilier 2007), last mile flows that deliver or pick-up retailing activities are estimated. Then, a shopping trip model (Gonzalez-Feliu et al. 2010b) is used to estimate shopping trip flows. Finally the substitution procedures described by Gonzalez-Feliu et al. (2012) are used to estimate the impacts of e-grocery distribution in terms of road occupancy rates, expressed in km. PCU (private car unit[3]).

The simulation of all the scenarios led us to propose a set of results which are reported in Table 1. The first column contains the identification of each scenario. Then, the road occupancy issues are estimated respectively for last mile B2B flows, B2C flows and shopping trips. Finally, the total road occupancy rates for all the flows are presented. Authors chose to not present all the B2B flows but only the last mile, assuming that all the organizational changes have an impact only on urban and peri-urban flows, so on last mile transport. Note that the reference scenario produces nearly 8.3 millions of in the Lyon urban area and that, in 2006, the downstream delivery flows were considered negligible. The road occupancy rates are extremely related with greenhouse gas emissions. More precisely, the proportionality between these two measures is shown in Routhier et al. (2009), where the impacts of shopping trips and lights goods vehicles are similar for both measures (in the reference situation of our scenarios, these trips represent 11% of the total road occupancy by moving vehicles (passengers and goods) of the urban area in Lyon and 11% of the greenhouse gas emissions, in tons of CO_2-equivalent

[3] PCU are standard road occupancy rates in France. The conversion rates are the following: 1 car = 1 PCU; 1 light goods vehicle = 1.5 PCU; 1 small truck = 2 PCU; 1 big truck = 2.5 PCU; 1 semi-articulated truck = 3 PCU.

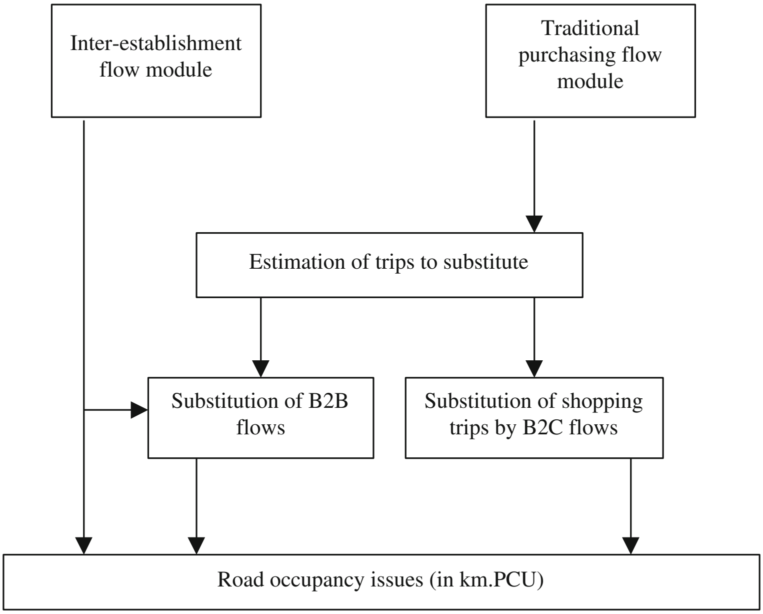

Fig. 3 Integrated simulation procedure chart (adapted from Gonzalez-Feliu et al. 2012)

emissions[4]). Moreover, a decrease on traveled distances and road occupancy has a direct impact on pollution, independently of the technological solutions (Gonzalez-Feliu et al. 2012).

It can be observe that scenario S1-1, which mixes HD and pick-up services, has a limited effect on road occupancy reduction (less than 4%) because of their location and geographical distribution (there are not enough proximity structures to ensure an efficient system). Scenario S1-2 shows the advantage of using specific platforms, which can be justified in medium-sized urban areas (from 500,000 to 3,000,000 inhabitants). More-over, avoiding store-picking for end-consumers implies a consequent reduction of shopping trips road occupancy rates (about 15%). However, B2C flows increase, and due to the vehicles used, which are bigger than private cars, this increase compensates a part of the reduction obtained for shopping trips. Furthermore, B2B flows representing less than 10% than end-consumer's flows, the big gains for these flows are not enough to compensate the increase due to B2B flows. However, the overall gains in terms of road occupancy reach 6%, almost the double that S1-1.

In this sense, scenario S1-3 shows the interest of using existing platforms for e-commerce with dedicated logistics schemes. However, the differences remain small (about 2.5% of difference in the total road occupancy rates), because of the

[4] Equivalent CO_2 takes into account the proportions of CO_2, CO, HC, NO_X and SO_X emissions, and their contribution to greenhouse effect (Routhier et al. 2009).

Table 1 Simulation results for the Lyon urban area, in millions of km

Scenario	Last mile B2B flows	B2C flows	Shopping trips	Total
S0	0.39	0.00	3.94	4.33
S1-1	0.36	0.26	3.55	4.17
S1-2	0.31	0.41	3.35	4.07
S1-3	0.33	0.28	3.35	3.96
S1-4	0.34	0.12	3.38	3.84
S2-1	0.35	0.26	3.41	4.02
S2-2	0.35	0.24	3.21	3.80

Scenario	B2B flows (%)	B2C flows (%)	Shopping trips (%)	Total (%)
S1-1	−9.0	6.7	−9.8	−3.7
S1-2	−20.2	10.5	−15.0	−6.0
S1-3	−16.8	7.1	−15.0	−8.5
S1-4	−14.6	3.1	−14.1	−11.3
S2-1	−12.3	6.5	−13.4	−7.2
S2-2	−12.3	6.1	−18.6	−12.2

PCU and in percentage difference with respect to the 2006 situation

hypothesis of e-grocery usage (15% of the total demand), so an overall reduction of 8.5% in terms of road occupancy. However, scenario S1-4 is the most advantageous of all single scenarios. Indeed, it results on a reduction of shopping trips of about 14% (i.e. near 1% less than S1-2 and S1-3) with a contained increase for B2B flows (about 3%) and a reduction of B2B flows also close to than S1-3 (about 14%), with a total impact translated on a reduction of near 11.5%.

If all these scenarios are combined following current practices (S2-1), it can be observed that nowadays there is not synergy logic and that each company develops its system without a "city logistics" viewpoint. This results on a total reduction of about 7%, which is close to S1-2. Only home delivery models being based on peripheral or non-urban platforms and city centers being congested several hours per day, it seems to favor proximity deliveries in the central zones and to give home delivery service to peripheries. For this reason, scenario S2-2 seems more favorable. To obtain an overall reduction of more than 12% it seems important to better combine the four alternatives. Although all alternatives operate in all the urban area, households privilege proximity reception points and proximity deliveries (simulated separately in S1-1 and S1-4) in the main urban area and in the near periphery. Moreover, home deliveries are privileged in the peripheral areas of the main city and in all the surroundings, avoiding to enter the city center for this home delivery vehicles, which are bigger that those of proximity home deliveries. More precisely, this scenario leads on a reduction of almost 20% of the shopping trip road occupancy rates with about 6% of increase for home and proximity deliveries.

4 Conclusion

This chapter presented an overview on the latest developments in e-grocery distribution and presented a scenario analysis using an empirical simulation approach. Four single scenarios, each of them related to a logistics model proposed by French e-grocery retailers are presented and simulated. It is shown that each single scenario has advantages and disadvantages to serve the different locations of the city. More precisely, scenarios S1-2 and S1-4 are more efficient in town centres and very populated and dense areas (both in terms of households and proximity retailers) because they are based on proximity retailer networks. Home deliveries (S1-2 and S1-3) are more efficient in household dense areas without a good proximity retailer density, i.e. in non central city areas and in near periphery surroundings. Because of logistics platform's locations, these two models are better than the other two for far periphery e-grocery distribution (proximity reception points or retailers are more spread in far peripheral zones).

Combined scenarios assessment shows that current practices (S2-1) do not profit of the synergies between each logistics model, leading to a total reduction of about 7% in terms of road occupancy, which is the third lowest impact. A better combination taking into account these possible synergies (S2-2) leads to an overall reduction of more than 12%. However, this scenario supposes that each company develops more than one logistics models, which can be difficult for co-operative and small stores like *Intermarché* and other franchising-based distribution companies.

Finally, authors have to note that in this simulation assumes development trends of e-commerce, which are realistic but remain still contained (15% of the total demand). According to Gonzalez-Feliu et al.'s (2012) results, and using the same simulation tool, it can be stated that a wider development of e-grocery will lead to a reduction of about 30–40% for road occupancy, on an hypothesis of 50% of e-grocery in urban areas).

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