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# Planning a sustainable reverse logistics system: Balancing costs with environmental and social concerns

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ABSTRACT

The present work aims to support tactical and operational planning decisions of reverse logistics systems while considering economic, environmental and social objectives. In the literature, when addressing such systems economic aspects have been often used, while environmental concerns have emerged only recently. The social component is the one less studied and rarely the combination of the three concerns has been analyzed. This work considers the three objectives and was motivated by the challenge of supporting decision makers when managing a real case study of a recyclable waste collection system, where strategic decisions on the number and location of depots, vehicles and containers were taken beforehand. Tactical and operational decisions are studied involving the establishment of service areas for each depot and the definition and scheduling of collection routes for each vehicle. Such decisions should represent a compromise solution between the three objectives translating a sustainable reverse logistics plan. The problem is modeled as a multi-objective, multi-depot periodic vehicle routing problem with inter-depot routes. A mathematical formulation and a solution approach are proposed. An approximation to the Pareto front is obtained for the case study and the trade-offs between the objectives are discussed. A balanced solution is proposed.



## 1. Introduction

Sustainability is nowadays an increasing society concern demanding for an active organizations posture. Within such context, logistics organizations play a crucial role, due to their importance in society. The design, plan and operation of sustainable logistics systems are then a challenge for the involved companies. To respond to such challenges, companies must effectively manage their logistics structures while considering economic, environmental and social objectives. Due to the complexity involved in the associated decision levels, tools that may support the decision-making process are required and represent an important defy to the academic community.

The concept of sustainability, although quite old, is commonly referred as defined in the Brundtland Report by the World Commission on Environment and Development (WCED) as “the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs” [1]. To achieve such goal the three dimensions of sustainability – economic, environmental and social – need to be considered when addressing sustainable systems [2]. This is not, however, a common approach in the literature. The majority of the published works on logistics networks has looked into problems with an economic view and, only in some cases, environmental aspects have been tackled [3]. Furthermore, literature addressing the social component is scarce [4].

Some authors have investigated the environmental dimension when studying logistics decisions. This is in the case of Frota et al. [5] who developed a framework for the design and evaluation of sustainable logistics networks, where profitability and environmental impacts are balanced. Dekker et al. [6] review the contribution of Operations Research to green logistics focusing on the design, planning and control of a logistics network. Bektas and Laporte [7] introduced the pollution-routing problem, where the cost of $CO_2$ emissions along with the operational costs of drivers and fuel consumptions are minimized when defining vehicle routes. Ubeda et al. [8] solve a vehicle routing problem with an environmental criterion minimization. Erdogan and Miller-Hooks [9] introduced the green vehicle routing problem, where an alternative fuel vehicle fleet is considered. A different way of reflecting environmental concerns in logistics decisions is to manage the returned product flow and/or integrate both forward and reverse flows in the supply chains. This topic has been intensively studied in the literature in recent years (see, for example, the works of Sheu et al. [10], Gu and Ji [11], Srivastava [12], Lee et al. [13], Salema et al. [14,15], and Qiang et al. [16]).

On the social dimension, Labuschagne et al. [17] categorize social sustainability issues into four main areas, being equity and safety within the internal human resources category, along with

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job opportunities, labor sources, diversity, discrimination, flexible working arrangements, research and development, career development, among others. Some of these aspects have been hardly explored within logistics systems. Ramos and Oliveira [18] study an organizational concern when defining service areas of a logistics system with multiple depots so as to pursuit equity. The authors state that balancing the workload (working hours) among depots is essential in problems with multiple depots, where the human resources, although part of the same organization, are fixed at each depot. A heuristic model to define depots service areas is proposed, where the minimization of the workload differences among depots is taken into account. Faulin et al. [19] address safety concerns when defining vehicle routes. These concerns are related with potential accidents in the workplace due to loading, unloading or handling activities. The authors state that avoiding workplace accidents will make logistics activities safer and healthier. Environmental concerns are also tackled, namely noise and polluting emissions. The safety and environmental concerns are translated into costs and a heuristic algorithm that optimizes the total cost is developed. Li et al. [20] address the social dimension in a truck scheduling problem for solid waste collection. A heuristic model is developed. This balances the collection routes assigned to recycling facilities in order to ensure that all recycling facilities receive solid waste, guarantying this way the jobs of deprived people in the different city areas. Equity can also be addressed when defining routes that minimize the maximum route length or minimize the difference between the longest and the shortest route lengths. Pasia et al. [21,22], Jozefowiez et al. [23,24] and Reiter and Gutjahr [25] study such problem, the so-called vehicle routing problem with route balancing (VRPRB), where two conflicting objectives are addressed: minimization of the total travel cost (or total tour length) and minimization of the maximum route length.

As referred by Garetti and Taisch [26], when only two dimensions are accomplished the system is said to be viable (economic with environment), equitable (economic with social) or bearable (environment with social) (see Fig. 1).

Under this framework, the designing, planning and operation of sustainable logistics systems, i.e., systems that take a position on economic prosperity, environmental quality and social justice are almost inexistent. The present paper aims to contribute to the reduction of this existent gap and aims to support tactical and operational planning decisions in logistics systems in order to make them sustainable: building less costly, more environmental friendly and more social concerned systems.

This work was motivated by a real case study of a recyclable waste collection system, where the problem faced was on the definition of the system service areas and associated collection routes that would support a sustainable solution, where not only economic objectives would be considered, but also environmental and social aspects would be accounted for. A multi-objective solution approach based on mixed-integer linear programming models is developed and applied to the case study. The economic dimension is modeled through the traveling distance that directly influences the variable cost. The environmental dimension is modeled throughout the calculations of the $CO_2$ emissions. Finally, the social aspect is considered by aiming to define a balanced solution in terms of working hours among drivers.

The paper is organized as follows. In Section 2 we present the case study that motivated the present work. In Section 3 we review the related work. The formulation of the multi-objective problem is presented in Section 4 and the solution approach described in Section 5. Then, the results obtained for the case study are presented in Section 6. Finally, some conclusions are drawn in Section 7.

## 2. Case study

The case-study that motivated the present work is based on a recyclable packaging waste collection system that can be generally defined as a system that, within a certain geographic area and on a regular basis, collects three types of recyclable materials (glass, paper and plastic/metal) dropped by the final consumer into special containers. The involved materials are then sorted, at sorting stations, and delivered to recyclers.

In Portugal there are several collection systems in operation, each one responsible for a certain number of municipalities. Our case study focuses on the company responsible for the recyclable collection system covering 19 rural municipalities with a total area of 7000 km$^2$. This company operates four depots and a vehicle fleet of eight vehicles. One of the depots operates also as a sorting station (depot 208). The remaining three depots are only transfer stations, where the recyclable waste is consolidated and afterwards transferred to the sorting station. The system involves 1522 glass bins, 1238 paper bins and 1205 plastic/metal bins spread over 207 localities (see Fig. 2). It is assumed that a collection site corresponds to a locality instead of an individual container in order to reduce the problem size. Due to the proximity of the containers within a locality (an average distance of 500 m) it is practicable to treat the containers to collect within a locality as a single node. The number of containers at each locality/collection site is a given parameter provided by the company. Regarding the quantities to collect in each collection site, they were obtained through the analysis of the historical database of the routes

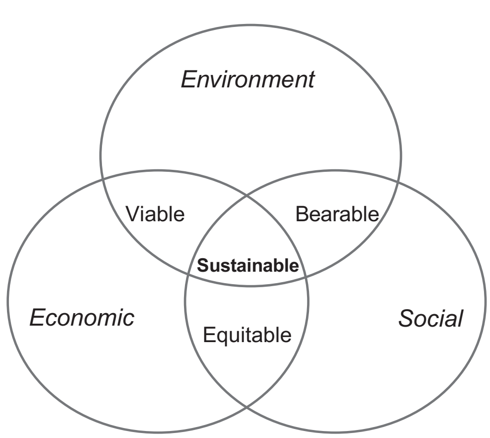


**Fig. 1.** The three pillars of sustainability [26].

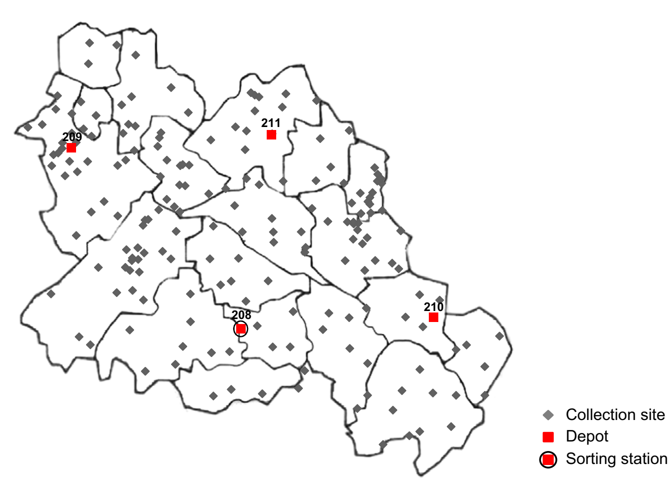


**Fig. 2.** Collection sites and depot locations.