Classification of Economic, Environmental and Social Factors in Vehicle Loading and Routing Operations

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Abstract. Sustainable Supply Chain Management has been recognized as a crucial research topic for the development of modern enterprises. This calls for the re-alignment of supply chain operations to include economic, environmental and social factors simultaneously. This paper analyzes how recent optimization developments have included sustainability related criteria regarding the integration of two of the most important supply chain activities: packing and routing of vehicles, and proposes a framework for classifying optimization criteria and operational constraints to aid in the inclusion of sustainability objectives towards the improvement of distribution logistics. Although the optimization of these two activities has been thoroughly studied by means of Vehicle Routing Problems and Container Loading Problems, their analysis is often done separately and considering only economic decisions in most cases. Individual optimization of these two operations may result in impractical solutions; while considering economic factors exclusively neglects environmental and social impact of distribution activities.

Keywords: Supply Chain Sustainability, Vehicle Routing, Container Loading, Systematic Literature Review.

1 Introduction

The distribution or transportation of products is a significant component of supply chains operations [1], and is an irreplaceable fundamental infrastructure for economic growth [2]. It is essential then to implement optimal distribution policies in order to lower logistics costs of the supply chain, but economic performance cannot be the only concern in distribution logistics. For instance, transportation has the most hazardous effects in the environment among supply chain operations [3]; and certain distribution conditions may have related social impacts, such is the case of delivery time windows which could reflect in longer delivery routes and may require that drivers work overtime [4].

Seeing that transport management has to deal with mode of transport selection, infrastructure, load planning, routing and scheduling operations [5], substantial efforts would be required in order to improve economic, environmental and social performance of distribution logistics. This is by no means an easy task for managers. However, concentrating on the packing of items in a vehicle and the subsequent route planning, which are the most important operations in distribution management [6], could serve as an interesting starting point. On account of this, managers would need tools that could allow them to determine simultaneously both the optimal routes and packing patterns of vehicles. This can be achieved by modeling and solving a problem known as the Vehicle Routing Problem with Loading Constraints (VRPLC) [7].

The VRPLC is a combination of two well-known families of problems: Container Loading Problems (CLP) and Vehicle Routing Problems (VRP) [7]. Despite the high practical importance of the problem, literature on the VRPLC has been limited [6]. Moreover, there is no evidence of work being done related to this problem that encompasses the economic, environmental and social factors at the same time. This combination is often referred to as the "triple bottom line" (TBL) objectives of sustainability [8], [9].

By performing a systematic literature review of recent optimization developments in VRPLCs, it is the purpose of this article to present a simple classification of the components of VRPLCs (optimization criteria and operational constraints) in terms of their economic, environmental or social nature, with the aim of providing a framework towards the implementation of robust TBL approaches in distribution logistics. The rest of the paper is organized as follows: section 2 gives a brief background of previous reviews on related problems. Section 3 explains the systematic literature review methodology used. Section 4 presents the general findings of the review. Section 5 presents the proposed classification for handling the structural characteristics of VRPLCs in relation to TBL objectives. Finally, section 6 concludes the article.

2 Background

Both VRPs and CLPs have been thoroughly studied in the literature. The reader can refer to the work by [10] for a classification of practical loading constraints and solution methods for CLPs. In addition, for a comprehensive classification of different variations and solution approaches for VRP, the work by [2] is also available in the literature. When dealing with load planning and vehicle routing decisions, a straightforward approach that managers could take would be to use CLP approaches for load planning and VRP for vehicle routing and then joining the individual results of each problem to make a unified decision.

However, focusing on individual loading and routing sub-problems may neglect structural dependencies between these two distribution operations and lead to suboptimal solutions [11], or, worse, to unfeasible solutions when looking at the integrated problem [12]. This shows a need to address the combination of the two problems, which can be done by analyzing VRPLCs. To our knowledge, the most recent review for this type of problems is the work by [7].

A closer look at these reviews shows that research has been carried out often considering only economic (production- and/or financial-based) metrics like minimization of operational costs, vehicle travelling time or distance, wasted space inside a container, among others. Furthermore, the inclusion of practical loading constraints defined by [13], which could improve these economic metrics and drive developments towards more realistic scenarios, is still insufficient in CLP approaches [10]. Nevertheless, the review by [2] mentioned a series of studies that have addressed not only economic type metrics but also environmental aspects related to overuse of energy and air pollution in VRPs from early as 2006.

Involving environmental factors in VRPLCs becomes especially significant considering that carbon emissions (i.e. Greenhouse Gas (GHG), CO_2) in transporting vehicles can depend on factors such as cargo loading, travelling distance and speed [14]. Also, amongst supply chain operations, transportation has the most hazardous effects on the environment [3].

It could be appreciated that two out of three of the TBL objectives can be identified in the cited reviews and studies, leaving out social factors. In the review process no evidence was found of VRPLC factors being treated from a social sustainability perspective, which supports the claim in [9] that social factors are the least studied factors when engaging TBL aspects of sustainability in supply chain contexts.

3 Systematic Literature Review Methodology

The review that was carried out followed the systematic methodology explained in [8], [15], [16]. In this sense, the research question for the literature review was defined as: *What quantitative methods have been used in the academic literature to solve loading and routing problems in the scope of sustainable development of supply chains?*

Furthermore, the review was focused on the identification of studies that used optimization methods for the improvement of loading and routing operations for sustainable supply chains. This resulted in the creation of search strings to locate documents in the scope of the topic for this review. Table 1 shows the keywords that were associated to the basic concepts treated in this paper. Finally, a general procedure was defined to select relevant documents from the search results. Relevant documents had to meet the following criteria: (i) written in English; (ii) journal articles or reviews available in full-text; (iii) the title and abstract were required to fit the topic of this review; and (iv) the operational issues had to do exclusively with vehicle loading and routing in road freight transportation.

4 Review General Findings

The search for documents was executed in the ISI Web of Knowledge database in May 2015 and considered documents published between 2003 and 2015. The findings presented here refer to a characterization of the documents in terms of optimization criteria and operational constraints. Table 2 shows the obtained general results. The reason for including both VRPs and CLPs in Table 1 and Table 2 and not only VRPLCs, is that if the loading pattern of a vehicle is assumed to be known *a priori*, a VRPLC can be reduced to a VRP; and vice versa, if the routing of the transporting vehicle is known, the VRPLC is transformed into a CLP.

Table 1. Used key terms

Concept	*Keywords*
VRP	Routing problem.
CLP	Packing problem; container loading problem; pallet loading problem; cutting problem; practical loading constraints.
VRPLC	Routing and loading problem; practical loading constraints.
Optimization criteria	Minimization; maximization; optimization.
Economic (Operational / Financial) factors	Costs; profit; container space, volume or area.
SSCM Environmental factors	Fuel or energy consumption; CO2, carbon or gas emissions; green; environment; pollution.
SSCM Social factors	Staff, worker, community, occupational or health safety or risk; working hours; fair or unfair salary or pay; labor or gender equity; social security metrics or policies.
SSCM	Sustainable development of supply chains; sustainable supply chain management.

Table 2. Search general results

Document type	*Number of documents*
Articles dealing with VRPLC	24
Unavailable articles dealing with VRPLC	4
Articles dealing with VRP only	40
Unavailable articles dealing with VRP only	13
Articles dealing with CLP's only	48
Unavailable articles dealing with PP's only	8
Articles with other operational problems	210
Unrelated articles	504
TOTAL SEARCH HITS	851

Short-listed papers are classified according to the optimization criterion (see Table 3) as well as to the considered operational constraints (Table 4). The set of criteria was defined by analyzing the selected papers from the review process. It is possible that a paper included several optimization criteria and/or operational constraints.

Table 3. Number of papers per optimization objective

Optimization objective	*VRP papers*	*CLP papers*	*VRPLC papers*
Min. total costs	24	10	18
Min. travelling time	3	-	3
Min. travelled distance	13	-	3
Min. number of vehicles/containers	6	5	5
Min. energy	2	-	-
Min. fuel consumption	5	-	-
Min. GHG emissions	1	-	-
Min. loading/unloading times	1	-	-
Min. driver overtime	1	-	-
Min. wasted space	-	26	-
Max. transported weight	2	1	-

Min. container size	-	9	1
Min. deviation of center of gravity	-	1	-

Table 4. Number of papers per operational constraint

Operational constraint	*VRP papers*	*CLP papers*	*VRPLC papers*
Capacitated vehicles / Container weight limit	35	5	22
Balanced vehicles / containers	1	1	-
(Split) pickup and (split) delivery	13	-	3
Backhauls	3	-	-
Stochastic demands	4	-	-
Skill required at node	1	-	-
Time windows	16	-	5
Travel dependent / Order release delay / Stochastic unload times	4	-	-
Intermediate stops	1	-	-
Limited route distance / duration	9	-	2
Road capacity	1	-	-
Item rotation allowed	-	31	13
Stability (Lateral / Vertical) of cargo	-	12	11
Item fragility	-	1	9
Item load bearing strength	-	4	2
Last In First Out loading	-	5	19
Weight distribution	-	5	-
Item grouping	-	2	-
Item priority	-	3	-
Arm-length distance for an operator to reach an item	-	1	2

5 Classification of VRPLC Characteristics for Supply Chain Sustainability

The classification presented here is done by considering the findings reported in the previous section, and the review by [9] on sustainability measures in global supply chains. In terms of optimization criteria, most papers addressed minimization of costs as their principal objective, which would be obviously related to economic aspects. Other criteria such as minimization of travelling time and efficient use of available container space can be classified also as being economic-related from what can be concluded from [17] and [18], respectively. Another example is the minimization of travelled distance, which could result in a reduction of fuel consumption and implicitly in a reduction of gas emissions, thus favoring economic and environmental sustainability at the same time. However, this must be explicitly and separately modeled as an environmental factor because shorter distances may not always minimize fuel consumption [19]. This supports the argument in [9], that exclusive consideration of costs is unsuitable when dealing with sustainability in supply chains.

In addition, the minimization of driver overtime could also be easily classified as an economic TBL factor. However, delivery routes may indeed need that drivers work some extra time [4]. These can create workload imbalance situations among the drivers, which could ultimately lead to worker dissatisfaction as stated by Kritikos and Ioannou (as cited by [20]). This implies that this kind of objectives can have a social impact and should be considered as such. In this sense, this objective could be treated simultaneously from both social and economic perspectives. Something similar can be said regarding the minimization of the deviation of center of gravity of the loaded vehicle or container. In road transportation, a proper weight distribution can provide better fuel efficiency and cargo integrity of the transporting vehicle [21]. This can impact safety of personnel and safe handling of the container [22], and minimize the possibility of a vehicle toppling over when driven around sharp corners [21]. This would mean that a proper weight distribution could be approached from all three TBL aspects. Fig. 1 shows the proposed classification for optimization objectives related to VRPLCs and how they should be considered.

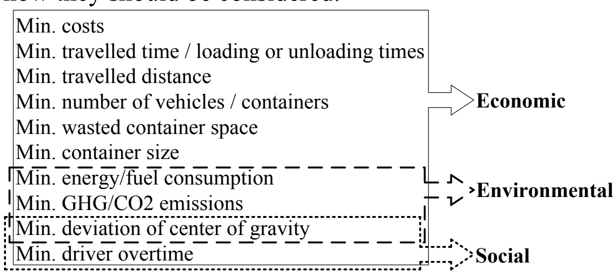

Fig. 1. TBL classification of optimization criteria

From the side of the operational constraints shown in Table 4, it can be stated that all of these constraints can work hand in hand to optimize economic aspects of VRPLCs. For instance, complying with client delivery time windows can avoid financial penalties [23], not respecting road capacity regulations may result on overhead costs due to the need of additional vehicles [24], or not managing stochastic demands correctly may incur in unexpected costs due to correcting routing actions [25]. Furthermore, constraints associated to loading conditions help guarantee that the generated loading patterns will preserve cargo from becoming damaged as it is being transported.

Constraints revolving around pickup, delivery and backhauls operations, limited route distance, stochastic demands, and time related conditions can also be paired with environmental objectives, as these might affect route distance and thus fuel consumption. Loading constraints dealing with container capacities, balanced containers or road capacity can affect travel speed and hence fuel consumption [19]. These practical routing and loading constraints are then related to TBL environmental objectives.

Additional constraints can be associated to social metrics. A special set of skills required at a delivery node and the need for a balanced vehicle fleet can be related to fair salary stipulations, worker dissatisfaction or both. Time related constraints like client delivery time windows, order delay, unload times and route duration can result in driver overtime. Weight distribution and the distance that an operator could extend his arm to reach an item can be related to worker safety. Summarizing, Fig. 2 shows the proposed classification for VRPLCs operational constraints.

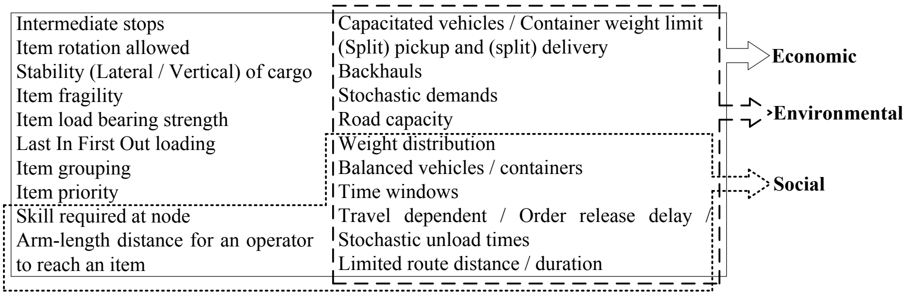

Fig. 2. TBL classification of operational constraints

6 Conclusion

Sustainable Supply Chain Management is a developing area of research with limited number of theories, models and frameworks [26]. There is still the need for the development of quantitative models for the optimization of supply chain operations [27] and the consideration of all TBL dimensions [26]. From a systematic literature review, a classification scheme of optimization criteria and operational constraints for VRPLC related problems has been proposed. Given the importance of this problem in the scope of supply chain operations, it is expected that this simple classification contributes to the academic and practical discussion for the inclusion of sustainability objectives towards the improvement of distributing logistics.

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