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Reverse logistics network redesign under uncertainty for wood waste in the CRD industry



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ABSTRACT

This paper addresses the reverse logistics network (RLN) design problem under environmental policies targeting recycled wood materials from the construction, renovation and demolition (CRD) industry. The main objective is to determine the location and the capacities of the sorting facilities to ensure compliance with the new regulation and prevent the wood from being massively landfilled. We formulated the problem as a mixed-integer linear programming model (MILP) to minimise the total cost of the wood recycling process collected from CRD sites. The main contribution lies in the consideration of important uncertain factors such as supply sources locations, the available quantity of recycled wood at the collection sites, and the various quality grades of the collected wood. A scenario-based analysis is conducted to evaluate the impact of uncertainties on the RLN design. In addition, the proposed MILP model has been applied for a case study in the CRD industry within the province of Quebec, Canada. The results of this study show the adjustment of the reverse logistics network leads to the reduction of wood recycling cost due to the improved efficiency of sorting facilities and the economy of scale achieved under the new policy. Moreover, sorting facilities are now located near the CRD collection points and not close to landfilling site as for the actual situation. Finally, the study demonstrates that efforts to obtain accurate information about the supply sources locations and the expected wood quantity recovered from sorting facilities will guarantee a more efficient RLN redesign.

1. Introduction

Nowadays, environmental regulations are emerging in many countries worldwide. The European Union Waste Framework Directive (EU-WFD) imposes a minimum of 70% collection of material waste in the construction industry (Supino et al., 2016). Turkey has recently seen the enforcement of the Waste on Electrical and Electronics Equipment (WEEE) regulation on its territory (Amin et al., 2017) and India is facing an increasing number of air and water pollution legislations (Greenstone and Hanna, 2014). Indeed, this is probably the most efficient solution to achieve more sustainable operations and force managers to take action to reduce the damage to the environment and avoid social problems caused by supply chain activities (Seuring and Müller, 2008). Waste management and recycling activities are usually connected with environmental regulations and many countries are putting a lot of effort into improving their efficiency in this area. Thus, we notice the emergence of many closed-loop supply chains (CLSC) in the past few years. The objective of CLSC is to combine the classical forward logistics flows with reverse logistics (RL) activities which are becoming very popular fields among practitioners and academics, both

of whom are trying to find better strategies to be in compliance with waste management policies.

This research addresses the specific problem of the management of wood waste by the construction, renovation, and demolition (CRD) industry. CRD is the first industrial waste generator in Canada, being responsible for a third of the total national waste generation (RECYQ-QUEBEC, 2012). Wood is frequently used as a building material in many countries, and more specifically in cold environments due to the advantages that are provided such as modularity, energy efficiency, etc. This is why countries such as Sweden, Denmark or Canada present a very high rate of usage of wood materials in their buildings (Sathre and González-García, 2014). In addition, with a very large territory and a lot of forest land, Canada is one of the countries with the highest rate of wood material inside its buildings (Yeheyis et al., 2013). Thus, wood is the first building material in terms of waste generated during the construction, renovation and demolition processes, often exceeding 30% of the total debris collected (Yeheyis et al., 2013). The recycled wood sector is facing some important challenges in Quebec. Today, more than 60% of wood generated at CRD sites is landfilled, partly because the recycling process is more expensive than the landfilling

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cost (RECYQ-QUEBEC, 2012).

Efficient RL networks have a major role to play in increasing the recovery rate of the recycled wood from the CRD industry. Indeed, in order to manage the wood recycling process in an efficient manner, we should be able to adequately locate the sorting facilities and decide on their annual treatment capacity. Dealing with transportation activities and building material flow between the collection sites and sorting facilities is usually a difficult task. It is even more complex in the CRD industry because of uncertainties in the reverse supply chain network. First, the location of the supply sources is variable over time, which means that they are different from one year to another making it complicated to locate the sorting facilities to minimise transportation distances. Secondly, the amount of wood material collected is highly unpredictable. Thus, the treatment capacity decision that must be allocated to each sorting facility to process the recycled wood is also a concern. Finally, according to the construction decisions that were made decades ago during the design stage of the buildings, the quality level of the collected wood on the CRD sites is highly unpredictable. The uncertainty of the location, quantity and quality level of wood generated in the CRD industry makes the recycled wood RL network design problem challenging.

Thus, the main objective of this research is to build a quantitative model for RL network redesign under an environmental policy that targets the recycled wood material from the CRD industry. To the best of our knowledge, this is the first study that addresses this specific problem targeting the CRD industry in this geographical area from a reverse logistics perspective. This research could be beneficial for the local authorities providing some useful insights about the expected impact of the environmental policy targeting the recycled wood material from the CRD industry, thus possibly preventing illegal dumping and border landfilling under the regulation.

To reach this goal, we propose a MILP formulation that allows making decisions at a strategic facility level such as 1) Should an existing sorting facility be closed or not? 2) Should we expand the treatment capacity of an existing facility? and 3) Should we relocate some of the existing facilities to decrease transportation distances in the RL network? Also, our model considers the RL tactical flow decisions between logistics units. The contribution of this work lies in two particularities. First, the model is able to capture both dynamic change in supply sources locations and also the variations in the quality levels of the collected wood materials. A scenario-based approach is proposed in this study to assess the potential impacts of these sources of uncertainty by selecting relevant discrete values of the uncertain parameters. The applicability of the model is illustrated with a case study in the province of Quebec, Canada.

The remainder of this paper is structured as follows. Section 2 presents the relevant literature review in the RL field. Section 3 presents in detail the mathematical formulation of the proposed model. Section 4 introduces the case study for the recycled wood from the CRD industry in the province of Quebec. Section 5 discusses some managerial insights based on the main findings. Finally, conclusions and future research perspectives are derived in Section 6.

2. Literature review

We have recently noted an increased number of research papers addressing RL problems and several literature reviews were also published in this field: Pokharel and Mutha (2009), Agrawal et al. (2015), Govindan et al. (2015). The first studies addressing network design problems in RL appeared less than 20 years ago (Barros et al., 1998). From this point, we denote an increased variation in the RL design models with collection centres and refurbishing facilities' location with multiple products consideration. Kara and Onut (2010) proposed a stochastic programming model to select a long-term strategy under uncertainties regarding the facility locations and the optimal flow in an RL network design problem with an application in the paper industry.

Lieckens and Vandaele (2012) developed a mixed-integer nonlinear program (MINLP) considering uncertainties on the collected quantities and quality of the products parts in order to make decisions about collection facility location. Lieckens et al. (2013) also proposed a MINLP that helps make decisions on reverse facility locations, capacity allocation and flow between the network nodes. The study of Toso and Ahem (2014) investigates both deterministic and stochastic capacitated facility location model considering discrete time intervals. Another stochastic programming model is presented in Dai and Wang (2014) that investigates the impact of uncertain collected quantity and secondary market demand for the returned products. A genetic algorithm is used to decide on collection point locations and flow decisions in the RL network. Later, Jeihoonian et al. (2016a, 2016b) also considered the unknown amount of returned products in a multi-stage stochastic model in order to locate the collection facilities in the reverse network. A scenario clustering decomposition is proposed to solve the multi-period model and its utility is illustrated in the sector of large household appliances. Fattahi and Govindan (2017) used a two-stage stochastic formulation to address the uncertainty related to new products demand and potential returns of used products. The proposed model is solved using a novel simulated annealing algorithm for large-sized problems. Finally, Nakatani et al. (2017) propose a robust multi-period formulation to address the optimal flow decisions in the context of uncertain demand and material prices. Table 1 shows that facility location and flow are the most common decision variables. Moreover, capacity expansion decisions are not very common in RL and CLSC models. The main sources of uncertainties are the demand and the collected quantity of the returned products in the RL network.

Very few papers address quality issues of collected products. However, to the best of our knowledge, studies that consider variation in the supply sources locations while making reverse network design decisions are unavailable. Indeed, this characteristic is very specific to the CRD industry. It is difficult to predict where the building materials collection points will be located in the future. Such feature has a real impact on the RL design decision. Indeed, transportation distances play a major role on the recovery rate of building materials as the building contractors will not accept to travel too far to the nearest sorting facility. Finally, we denote a significant number of decision models that are applied to industrial case studies, sometimes for a specific sector or from a more general perspective, without targeting a particular product category. In Table 2 we reviewed 103 papers in the RL and CLSC fields by industrial sector.

We can clearly see the lack of case application in the CRD industry. Only the research of Sinha et al. (2009) proposes a stochastic formulation to design an RL recovery network in the construction sector. Although the proposed model considers demand and return uncertainties, supply sources locations change and quality issues are not addressed. However, information about material waste quality is a key element in the construction industry in order to manage RL activities properly (Sobotka and Czaja, 2015). There is a need to address this gap in order to build an appropriate model for this particular sector, showing some specificities compared to the traditional reverse logistics practices applied to the manufacturing industry (Hosseini et al., 2014).

In order to minimise the RL costs of the wood building-material recovery process and to ensure compliance with the legislation, it is critical to develop innovative models that consider the particularities of the CRD industry: unpredictable quality of the recycled wood material collected, the variable location of the supply sources and the collected quantity of materials.

3. Model development

3.1. Assumptions

In order to build a model adapted to the reality of the wood building-material recycling supply chain, we consider a RL network

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