On the reverse IRP of collecting hazardous recyclables

Environmental concerns, legislative measures and economic reasons have led to an increase in recycling and reuse efforts.

This favored the development of reverse logistics systems, and in the same time pushed forward different initiatives and ideas about making reverse logistics efficient and cost effective.

As it is stated by Thierry et al. (1995), the concern for the environment led companies to be interested in environmental aspects of their operations. Therefore, different activities that companies perform need to be analyzed from environmental perspective, particularly those related to logistics. This becomes more obvious if one considers reverse logistics definition as “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 or creating value or proper disposal" (Rogers and Tibben Lembke, 1999). Actually, the development of distribution channels and systems for the recycling industry was first mentioned much earlier (Guiltinan and Nwokoye 1975). This was a time when the industry did not feel obligated to governmental regulations and customer perspective on environmental issues. After the first legislations of environmentally conscious production and manufacturing (ECP/ECM) were introduced, ECP/ECM began to draw the attention of production researchers and practitioners in early 1990s.

Reaching environmental goals and achieving economic effects is mostly related with the increase of the quantities of end of life (EOL) products collected, while reducing logistics costs. Hence, a key element of reverse logistics system is the collection of used products discarded by last owners or consumers. Also, it is the first activity of reverse logistics that triggers the others (repairing, remanufacturing, recycling …).




However, collecting itself, although very important isn't enough. Providing adequate treatment of EOL needs also efficient and economical transport of collected materials. It is why the most of papers dealing with collection issues in reverse logistics are focused on vehicle routing problems and its applications on specific problems. Beullens et al. (2001) presents a survey about collection and vehicle routing issues in reverse logistics. Teixeira et al. (2004) describes a study of planning vehicle routes for the collection of three types of recyclable waste in Portugal. Krikke et al. (2008) discussed an application of remote monitoring of inventory levels in reverse logistics to improve the collection efficiency of the mandatory collection of dismantled materials. Aras et.al. (2008) formulate mixed-integer nonlinear collection center location problem (CCLP) to find both the optimal locations of a predetermined number of collection centers and the optimal incentive values for different return types. Recently, Vidovic et.al (2015), proposes location-routing model for designing recycling network with profit. Proposed model simultaneously determine collection points' locations with distance-dependent returns, location of intermediate consolidation points (transfer centers) and the route of the collection vehicle so as to maximize its profit from the collection of recyclables.

On the other hand, a part of reverse logistics flows are related to dangerous, or obnoxious substances that are, while transported and stored, represent risk to the environment, individuals or properties. In this case, establishing logistic networks require appropriate approaches that can give solutions while respecting not only economy, but risk as a one criterion as well. This concept, which includes hazardous materials (or dangerous goods) is extremely important because of potential consequences to the environment. Hazmat logistics and risk minimization concepts have been a very active research area during the last thirty years. Numerous special issues of refereed academic journals were focussed on hazmats. For more detailed insight in this area, to the interested reader we recommend book chapter of Erkut et.al. (2007).

There are two concepts dealing with risk in logistics processes. Risk minimization concepts, both in facility location and transportation context are considered by numerous researches in the last thirty years. Concepts and approaches to risk equalizing have been also subject of intensive research during last three decades. For example, Keeney (1980) expresses equity as the magnitude of the largest difference in the level of risk among a fixed set of individuals. Approach to the modeling of risk, equity and efficiency in facility location and transportation of HM, can be found in Current J., Ratick S. (1995).

The local routing problem is to select the route(s) between a given origin destination pair for a given hazmat, transport mode, and vehicle type. Thus, for each shipment order, this problem focuses on a single commodity and a single origin–destination route plan. Since these plans are often made without taking into consideration the big picture, certain links of the transport network tend to be overloaded with hazmat traffic. This could result in a considerable increase of accident probabilities on some road links as well as leading to inequity in the spatial distribution of risk. Although large-scale hazmat carriers are known to consider transport risk in their routing and scheduling decisions, transport costs remain as the carriers' main focus.

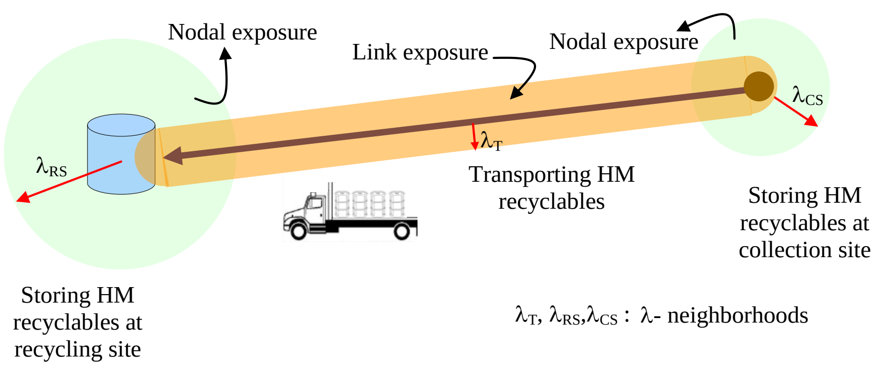
In contrast, the government (municipal, state/provincial, or federal) has to consider the global problem by taking into account all shipments in its jurisdiction. This leads to a harder class of problems that involve multi commodity and multiple origin–destination routing decisions. In addition to the total risk imposed on the public and environment, a government agency may need to consider promoting equity in the spatial distribution of risk.

Our research has been focused to the problems of simultaneously defining inventory levels, and transport schedule under criterions of risk minimizing or equalizing. More specifically, research was oriented to integrated Inventory Routing Problem (IRP), where the idea is to simultaneously solve problems of optimal quantity and time of delivery of goods, as well as the problem of optimal scheduling of vehicles. However, here, the objective of finding balance between inventory and transport costs is widened by introducing additional, risk criterions.

This general research concept has been divided into three directions analyzed in this bilateral project. One was devoted to the further extension of the previous research related to Reverse Logistics Inventory Routing Problems Under Risk conducted by team members from the Serbian side. Another research direction was devoted to forward logistics, where we analyzed Petrol Stations Replenishment, under criteria of risk minimization. Finally, the third research direction is related to possibilities for extending location-routing model for designing recycling network to the case when recyclables belong to the class of dangerous goods.

In the case of Reverse Logistics Inventory Routing Problems Under Risk we analyzed supplying recycling facility with collected recyclables accomplished by a fleet of trucks. Recycling process required that products are returned in the best possible condition in quantity and supply frequency which provide continuity in the treatment process. Finally, the products need to be transported in a cost-efficient and environmentally friendly way to the treatment facilities of the reverse logistics network. In this problem, the cost efficiency was related only to the transportation cost, because of low value of recyclables. However, while low valuable recyclables tend to increase inventory level in the system, higher risk imposed by larger quantities of hazardous recyclables require decreasing average inventories level in all network nodes, as well as making trade-off between frequency of supplies and quantity of recyclables in each supply. Therefore, it becomes obvious that solving the problem means finding balance between providing continuity of recycling process, transportation costs, inventory level, and risk imposed by transporting and storing hazardous recyclables.

In the context of HM, risk is a measure of the probability and severity of harm to an exposed receptor due to potential undesired events. The exposed receptor can be a person, the environment, or properties in the vicinity. Widely used assumption that aids estimation of consequences is that in the event of an accident the HM has a radius of spread that depends on physical and chemical properties of the substance in question. If λ represents the radius of spread, receptors within the boundary of a circle with a radius could potentially be affected. For travel on a link, we could speak of a whole λ-neighborhood that is endangered. The λ-neighborhood is a concept (figure below) developed by Batta and Chiu (1988), and it is used when calculating risk in our model. Two types of risk need to be taken into account in integrating inventory level at storing sites and routing decisions pertaining to HM recyclables supply: transport risk R_{ij}^{T} on the link (i,j), and storing facility j risk R_{j}^{F} .



Although in most cases, the HM has a radius of spread (r) proportional to the third root of its quantity (Q), in this research it is assumed that the radius of spread in case of storing facility is a function of the square root of quantity i.e. $r \cong \sqrt[2]{Q}$, similarly to the idea deployed by Current and Ratick (1995). This approximation gives opportunity to easily calculate risk R_{j}^{F} imposed by storing facility j as a area of circle of the radii $\sqrt{Q_j}$:

$$R_j^F = \alpha \pi Q_j$$

where

α is a density of exposed receptors (population, properties,…)

Q_j quantity of HM recyclables in storing facility j

In the case of transport risk computation radius of spread is consequence of the vehicle capacity. When assume reasonable use of vehicles which are loaded close to its capacity q_k, imposing radius of spread of r_k, then transport risk R_{ij}^{T} on the link (i,j) in each trip can be calculated as:

$$R_{ij}^{T} = \alpha(2r_k d_{ij} + \pi r_k^2) \tag{3}$$

r_k radius of spread which corresponds to the vehicle of capacity of q_k

d_{ij} length of the link (i,j)

The shown approach used in risk computation, obviously, does not respect accident probability but assumes accident certainty. This fact gives opportunity for further improvements in mentioned areas: analyzing effects of accident probability introducing, and analyzing another possibilities to approximate radius of spread. Finally, our intention was to improve our previously formulated model by allowing vehicles to visit more than one collection point in the same route. Contributions related to mentioned topics is still in research phase and part of our ongoing activities.

In the case of Petrol Stations Replenishment, under criteria of risk minimization we observed risk assessment in petrol stations replenishment as an important segment due to hazardous nature of fuel. In this way, we extend our previous research (Popović et al. 2012, Vidović et al. 2014) where we observed only inventory and routing costs in IRP for petrol stations replenishment, to include risk minimization by two additional performances that have significant influence to possibility of accidents: vehicles' total travel distance with fuel and number of replenishments. Furthermore, we assume that risk is more important than the costs and therefore objective function must primary minimize the risk and secondary minimize inventory and routing costs.

We proposed modeling approach to solve the problem of obtaining delivery plan of different fuel types from depot/refinery to set of petrol stations using homogenous fleet of vehicles with compartments in planning horizon of several days. This decision must respect risk minimization which is expressed in vehicle total travel distance with fuel and number of stations replenishments, as well as inventory and routing costs minimization. Inventory costs are observed as holding costs and routing costs depends on vehicles total travel distance. Solution of observed problem consists of two segments:

- fuel quantities to be delivered in observed planning horizon;
- and vehicle routes in each day of planning horizon.

In the observed problem one petrol station can be served by a single vehicle in each day of planning horizon (split deliveries are not allowed). We assume deterministic daily fuel consumption for each station and fuel type. Each petrol station has underground reservoir ow known capacity per each fuel type. Fuel stock-outs and backordering are not allowed. Because we assume deterministic fuel consumption, whereas in real life consumption has stochastic nature, each petrol station per fuel type must have adequate safety stock equal to the daily fuel consumption. Fuel is transported by vehicles with compartments of identical capacity, where each compartment is fully loaded with one fuel type. Entire compartment content must be unloaded at one petrol station or, in other words, splitting the content of one compartment to more than one station is not allowed. Vehicle fleet is limited and multiple vehicle use per day is not allowed. Number of compartments K can usually vary from 4 to 6 (Cornillier et al. 2008) and therefore we tested the model with three vehicle types (of similar total transportation capacity).

Maximal number of stations per one route is a common restriction in practical petrol stations replenishment, where usually each route can service up to three petrol stations (Cornillier et al. 2008, Vidović et al. 2014). This restriction is also used in our model.

Proposed MILP model is based on assignment formulation with two main binary decision variables. The solution of observed problem must allocate stations to be served, to vehicle's routes in each day of planning horizon. This is achieved by y_{pt}, y_{pqt}, y_{pqwt} decision binary variables that represents vehicle routes in day t, respectively: direct vehicle route to station p; vehicle route with two stations p and q; and vehicle route with three stations p, q and w. At the same time, servicing a petrol station means delivery of compartments (with a fuel type) to petrol station. These deliveries combined with fuel consumption have impact on inventories at those stations. To model inventory segment we use x_{ijtk} decision binary variable that represents compartment quantity k to be delivered in day t for petrol station i and fuel type j.

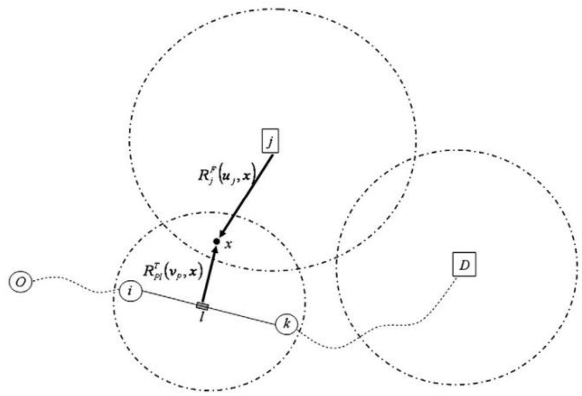
The order of stations in the indices of y_{pqwt} variables does not represent the service order of those stations in observed vehicle route. Instead, we use enumeration to determine the shortest path of vehicle with fuel in compartments for those variables. The total travel distance of vehicle (including "empty" kilometers when vehicle is returning to depot from last station in the route) is calculated by adding the return trip to the shortest path of vehicle with fuel. These values are then an input to proposed MILP model as coefficients. In that way, we reduce model size. Objective function of proposed MILP model is comprised of three segments: risk approximation which is the primary segment of optimization; inventory costs; and routing costs.

Regarding the routing and inventory costs, we observed the case where vehicle's cost per travelled kilometer is 2 €/km while daily inventory holding cost are 1 €/1000 l. Risk minimization segment of objective function is not represented as costs, but as a number of replenishments and a number of travelled kilometers with fuel. Therefore, it cannot be incorporated as it is in objective function together with costs. Moreover, risk should be more important than costs and this is why we use weights W_1 and W_2 to increase the importance of risk segment. Different combination of these weights can lead to different results and therefore we have tested the model with the following values: W_1={0, 5, 10, 20, 50, 100}; W_2={0, 50, 500, 1000, 5000}. Results of our research show that vehicle type with more compartments (K=6 & Qo=5800 l) has better performances regarding both costs and risk aspects in observed problem. Regarding the impact of W_1 and W_2 values on the results, two risk segments are mutually conversely dependent. In other words, an increase of W_1 vales leads to smaller values of total distance with fuel and greater values of number of station replenishments, and an increase of W_2 has opposite impact. Furthermore, minimization of either of two risk segments leads to increase of total costs, while higher values of W_1 or W_2 incur higher total costs.

The main idea related to the third research direction is to extend and adjust our previous model which simultaneously determine collection points' locations with distance-dependent returns, location of intermediate consolidation points (transfer centers) and the route of the collection vehicle to the case when returns are hazmats, which means that location routing decisions require risk consideration.

In general, the location–routing problem (LRP) involves determining the optimal number, capacity, and location of facilities as well as the associated optimal set of routes (and shipping schedules) to be used in serving customers. The LRP is NP-hard and offers a variety of challenges. The literature addressing LRP with different real-world applications has evolved since the late 1960s. Christofides and Eilon (1969) were among the first to consider LRP with multiple customers on each route. Also, extensive research in this area continued through decades, and it is also very active. The most recent researches (Samanlioglu,2013; Alumur & Kara ,2007 ; Zhao & Verter, 2014).

Two types of risk need to be taken into account in integrating location and routing decisions pertaining to hazmat shipments: transport risk, and facility risk, as it can be seen from the figure (adapted from List and Mirchandani, 1991).



An individual at point x is exposed to a transport incident on a nearby route segment l of a path P that involves a vehicle carrying volume v_P and an incident at the hazmat treatment center at site j with capacity u_j.

The transport risk can be determined as a function of the undesirable consequence at point x, taking into account the impact zone of a hazmat incident on segment l. The facility risk, can be determined in a similar way, with site j replacing the route segment l. In this way List and Mirchandani (1991) proposed a hazmat LRP model that simultaneously considers total transportation and treatment risk, total transportation cost, and risk equity. Risk equity is enforced by minimizing the maximum consequence per unit population for all mutually disjoint zones of the transportation network. The model is more general since it allows for different types of hazardous materials and treatment technologies. This model assumes that the impact to point x in a zone Z from a vehicle incident is inversely proportional to the square of the Euclidean distance between the vehicle and point x, and the impact is directly proportional to the volume v_P being shipped regardless of material.

Therefore, the third research direction should be understood as an attempt of joining shown general hazmat LRP concept, and the model which simultaneously determine collection points' locations, location of intermediate consolidation points (transfer centers) and the routes of the collection vehicles.

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