Optimization Criteria in End-of-Life Products Reverse Logistics Network Organisation

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The paper discusses the problem of selection of objective function in modelling of the reverse logistics network entity location. A growing ecological awareness of societies as well as implementing concepts of manufacturer responsibility for their products result in a creation of systems of collecting and treatment of end-of-life products. Rather than being a random process a reverse logistics network should be designed as an effect of informed decisions taking into account all aspects and points of view of the stakeholders. A key issue in network design related to the use of decision support tools based on mathematical optimization is the appropriate selection of the objective function for evaluation of the potential solutions.

Keywords: reverse logistics, optimization, objective function.

1. INTRODUCTION

The importance of reverse logistics has been growing since 1990s of the last century. It is estimated that in the US the costs of reverse logistics are equal to 1% GDP [10]. More and more products go upwards in the logistic chain, mainly due to the growing customer requirements (purchase return options, service, warranty) and environmental issues (recovery of the end-of-life products).

In many cases it is impossible to use the original new product distribution channels for reverse logistics. This is particularly the case for waste material. The collection and disposal of the end-of-life products most often require a creation of an appropriate recycling network independent of the production and distribution networks. The main problems that need to be solved are the determination of the number of links in the chain (e.g. resolving the question whether special return, sorting and waste treatment entities are to be created), number and location of the network entities on individual levels and the financing principles related to reverse logistics.

2. REVERSE LOGISTICS

Processes related to waste collecting and transport as well as location and selection of waste disposal entities are within the realm of reverse logistics. Reverse logistics is related to the creation of added value in a opposite direction to the initial flow in the logistic processes [9].

A classic definition of logistics characterizes it as a process of planning, implementing and control of efficient and cost effective flow of materials, inventories in progress, final goods and related information from the point of production to the point of consumption in order to adapt it to the needs of the recipients [11]. According to this traditional definition the logistic process ends in

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the moment when the product goes in the hands of the consumer.

The reverse logistics consists of all of the above-mentioned actions. The difference is that the reverse logistics sees them as working in the opposite direction i.e. from the consumer to the supplier. That is why, by the term of reverse logistics we understand a process of planning, implementing and control of efficient and cost effective flow of materials, inventories in progress, final goods and related information from the point of consumption to the point of production in order to recover a value or with a view to proper disposal. This is not, however, a typical reversing of the direction of the flow, hence the issue is far more complex than it seems.

collection points- return stations) the product has to be delivered to the manufacturer or other entities that will ensure proper disposal of the products returning to the logistic chain. A manufacturer receives products in warranty claims or product returns, but other entities such as recycling and recovery facilities receive used up goods and those withdrawn from the market.

Traditional logistics and reverse logistics have certain common characteristics but there are also significant differences between these two. They mainly pertain to the size of the deliveries, their predictability and required information [7].

Companies devote much attention to the traditional distribution logistics – it is carefully planned, analyses and cost audits are made while the reverse logistics is treated with less care. This results from the fact the in the case of reverse logistics we face the element of randomness– we do not know how many goods will have to return to the manufacturer or the seller and when the return will take place. Besides, in the case of returns and warranty claims the flow of goods in

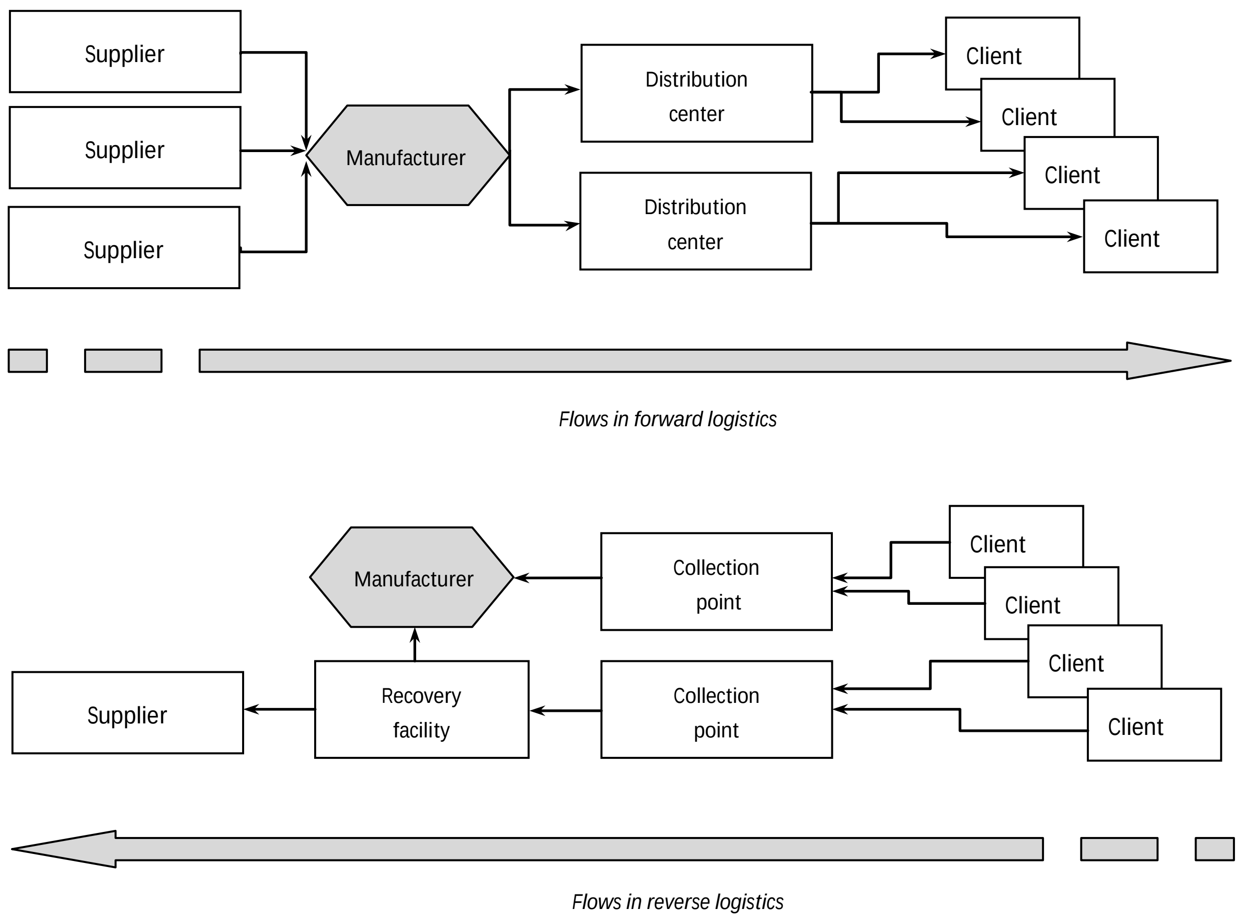

Fig.1 Forward versus reverse logistics flows

In traditional logistics referred to as forward logistics the manufacturer receives raw materials and half products from its suppliers and then distributes finished products to a multitude of outlets from where they go to many end users. In the reverse logistics this process is reversed i.e. from many scattered end points (consumers or the reverse direction is much smaller than in the case of forward logistics. Another difference is related to the fact that with reverse logistics the manpower use converted into the units of goods is much higher. It is due to the fact that in each case an additional evaluation and verification of the goods takes place and, for the waste material, very often a manual disassembly is necessary. Some other differences between forward and reverse logistics is the necessity to cooperate with the client that has to supply the product to a given collection point (return station) or leave it at the disposal of the carrier (collector). Proper packaging issues may occur as well. Finally, the characteristic feature of most of the returned goods in the logistic chain is their lower value as compared to the initial product [4].

Depending on the reason for the return of the goods into the logistic chain we can differentiate the following types of reverse logistics:

- reverse logistics of returned goods (faulty products, change of the customers purchasing decision- mail order sales, return of books in a sale or return system);
- reverse logistics of goods under warranty claims– returns arising from faulty goods under warranty or manufacturer's guarantee, goods recalled by the manufacturers because of their malfunctions or defects;
- reverse logistics of waste– may result from legal regulations or economic conditions when it is economically justified to recover goods from waste material e.g. return of used batteries, electronic equipment, household appliances or end-of-life vehicles;
- reverse logistics of packaging– similarly to the waste material reverse logistics, may result from legal regulations or the will to reuse the packaging in a production cycle – return of bottles.

The return and warranty claim reverse logistics differs from the waste reverse logistics. In the return and warranty claims logistics, if the product return because the customer changed his mind about purchasing it, it is redistributed in the sales network and in the case of a warranty claim the product is returned to the manufacturer and (if not beyond repair) is repaired, packed and redistributed in the sales network. The redistribution into the sales network may take place through traditional outlets or in a different form (auction, internet sales, special redistribution outlets). In the reverse logistics of waste material as well as in the case of unrepairable warranty claims, the reverse logistic process will include a disassembly, sending of selected items to appropriate recovery and recycling facilities or disposal sites. In the case of some types of reverse logistics such as client decision-related returns, the same logistics chain is used in practice as in forward logistics. In the case of waste material logistics the end-of-life products may go to entities entirely different than the product manufacturers and the manufacturers' distribution network. Hence, these are two entirely different logistic chains characterized by different processes and different participating entities.

The reverse logistics of the waste material combines a classic approach to the logistic actions with actions related to the collection and treatment of the waste resulting from the necessity to protect the environment. It is thus a process used while collecting end-of-life products like vehicles or white goods and managing the collection and treatment of waste materials contained in these products.

Within the waste related reverse logistics the following waste management actions are taken:

- collection,
- sorting,
- verification,
- forwarding to the facilities responsible for the waste management (recycling or energy recovery) or scrapping (safe disposal or combustion without energy recovery),
- monitoring of the process,
- preparing of reports and providing information.

All entities responsible for collection and treatment of waste form a recycling network of end-of-life products.

3. SELECTION OF THE LOCATION OF ENTITIES IN REVERSE LOGISTICS

Creating recycling network requires certain decision support tools. The decisions related to the location of the entities should be based on as many technical, economical, ecological and legal factors as can be. Hence, the creation of a selected fragment of the network e.g. in the aspect of its extension or location of new entities will ensure maximization of benefits from both the point of view of the network participants, the vehicle owners and other stakeholders.

The search for the solution of a decision-making problem (recycling network structure element location) requires determining of the objective function that will constitute the decisive criterion as to which of the feasible solution is the optimum one. This function is thus an indicator of the solution quality evaluation.

An optimum solution is a solution for which the adopted quality evaluation criterion (e.g. minimum cost) reaches an extreme value when fulfilling [8]:

- limitations of the network (e.g. throughput potential),
- constraints resulting from the demand for waste processing (for example the quantity and mass of the waste to be treated),
- constraints resulting from the physical interpretation of the quantities (e.g. non-negativeness).

The optimization criterion is a reflection of the preference function of the decision-making entity. Depending on the number of preference functions used as partial criterion functions we can distinguish single criterion and multicriteria optimization tasks. Single criterion tasks are those that use only one objective function deciding about the selection of the optimum variant.

In multicriteria tasks several preference functions are included at a time that very frequently reflect contradictory views. In models of this type two or more partial functions are extremized at the same time but improvement of one objective function cannot be done without simultaneous detriment to at least one of the other objectives. The decision is thus made in the context of simultaneous realization of all partial criterion functions and usually there is no decision (solution or action) that is optimum from all points of view. Contrary to the classic operational research techniques, multicriteria methods do not provide the best solutions. The proposed solutions are a compromise of the preferences of the decision makers or other stakeholders.

4. OBJECTIVE FUNCTIONS IN THE REVERSE LOGISTICS ENTITY LOCATION

It is noteworthy that in the 1960s 1970s of the last century the basic and virtually only criterion in the optimization of waste recycling network entity locations was the minimization of costs [2]. It was only in 1980s, when the ecological awareness of societies grew, that other aspects, mainly the ecology-related ones were taken into account. Yet, this was the 1990s that the real development of models based on environmental aspects blossomed. In waste system planning, environmental requirements such as noise emission, air pollution and transport congestion were included as limitations in the economically oriented location of the system entities.

Single criterion optimization tasks, despite a continuous development of multicriteria models, are still more frequently applied in practice due to their simpler formulation and realization process and faster and easier finding of optimum solutions.

When using a single criterion modelling of a recycling network one function is selected out of the potential objective functions and is subsequently subject to minimization or maximization maintaining the assumed constraints. In the multicriteria methods in network modelling the criteria are selectively put together forming partial criteria.

Despite the possibility of selection of different types of objective functions, the analysis of the available research works on network creation in reverse logistics carried out by Chanintrakul and others [3] has shown that in single criterion models the objective function is almost always the minimization of costs. Most frequently the cost minimization is limited to the cost of the mere transport of the waste and sometimes the cost of transport and storage. The costs of recovery comprising the costs of logistics and treatment are much less frequently used. The best scenario is when the objective function is related to the total costs i.e. it comprises both the overheads and variable costs. The overheads most often include the initial investment (the costs of operation start-up) expressed with depreciation and the costs of running the operation independent of the production scale (expressed with the size of the provided services, size of the production, amount of processed waste). Variable costs include: transport, maintenance costs, service costs, distribution costs, storage costs or environmental costs (e.g. related to the neutralization of waste).

Other criteria that can be used in single criterion tasks of reverse logistics entity location as partial objective functions in multicriteria tasks may be:

- Minimization of environmental risks – related mainly to the minimization of the transport risk - the transport of waste, storage and processing of waste and minimization of occurrence of undesirable effects (noise, toxic emissions) both at the stage of transport and processing.

- Maximization of coverage – in this case it may have a geographic (distance area), temporal or quantitative (satisfaction of demand) context. Within this group maximization of distance and service provided to the population is most often used. In this group we can also include the criterion of even distribution and dispersion because this preference is also related to the problem of coverage (the only difference is that the coverage is even).
- Maximization of the quality of services provided and effectiveness of the processes – these criteria include maximum use of the infrastructure or maximization of indexes related to the range of provided services.
- Maximization of profit – related chiefly to the maximization of net profit, maximization of return from capital investment as well as maximization of revenues.

In multicriteria tasks, when selecting a set of partial criteria, we need to adhere to certain rules. Roy proposed using a family of criteria that are exhaustive, coherent and non-repetitive [12]. These rules were extended by Bufardi and others [1], according to whom the partial objectives should be:

- complete – should take into account all significant points of view of people or organizations that influence the decision making problem (otherwise exhaustive),
- non-repetitive, i.e. should not measure the same phenomena,
- limited to minimum in number so that the size of the decision making problem is as small as can be,
- operative i.e. measurable and, in terms of meaning, interpretable in analysis,
- differentiating solutions – criteria giving the same values to all alternative solutions should not be considered.

It is not always possible to determine a set of totally independent criteria, as there usually exists a certain codependence among them. We should then select those criteria whose relation is minimum.

In the case of complex systems (the reverse logistics network belongs to this category) and irrespective of what the subject of the optimization is (the adaptation of the infrastructure to the needs, entity locations and their effectiveness) it is hard to propose a single criterion that will satisfy all stakeholders. The preferences of government offices, owners of the waste material, manufacturers or recycling network participants differ. A growing awareness of the society and a widespread implementation of the concept of sustainable development in the developed countries have caused that the design of a recycling network cannot be done based exclusively on the desire of the entities to participate in the system and their individual profit account. Such entities take their decision based on the profitability analysis that should not be the only criterion deciding about the network entity location.

Many involved parties that are interested in the functioning of the network present many points of view of the participants of the recycling process, each of which strives to extremize their individual benefits. Multicriteria approach to decision support assumes a minimization or maximization of the objective function composed of many partial criteria. The criteria of reverse logistics network structure optimization may differ depending on which point of view we assume when evaluating the recycling network.

In practice, in bi-criteria tasks, the most frequently applied partial criterion functions are as follows [5,6]:

- minimization of costs and minimization of process time,
- minimization of costs and maximization of geographic coverage,
- minimization of costs and minimization of negative local impact,
- minimization of costs and minimization of distance between the network elements.

The objective functions used in the optimization of recycling network entity location both in single criterion optimization tasks as well as partial functions in multicriteria tasks can be divided into three groups. The first one comprises economic criteria related to the costs of the creation and functioning of the infrastructure, costs related to the material flow in the network and generated revenues. In the second group we find criteria related to the environment protection and the third one includes process evaluation criteria.

Economic criteria

- Minimization of the costs of infrastructure creation – pertains exclusively to the initial capital investment for the creation of the infrastructure of the recycling network (equipment, buildings, cost of permits) but it does not include the costs related to the functioning of the enterprise.

- Minimization of the costs of waste recovery – pertains to the costs of ongoing activity related to the processes of waste recovery. It includes overheads, variable costs, and the costs of transport.
- Minimization of the total costs of waste management – this criterion is similar to the criterion of minimization of the costs of recovery but it additionally includes the costs of waste disposal that are not to be recovered through the recycling network.
- Minimization of the costs of transport between the network elements – the costs of transport are very often a barrier in waste recovery as the revenues from the sales of the recovered parts and raw materials do not cover the expenses of their transport between the network elements.
- Minimization of the costs of transport of the waste to the collection points – the above criteria were related to the minimization of costs incurred by the network participants or its organizers but this criterion of cost minimization is used by the owners of the waste material. These costs cover mainly the costs of transport but they may also include charges due when returning the waste material to the recycling network.
- Maximization of revenues – a very important criterion from the point of view of the self-financing of the recycling network as the amount of generated revenues from the sales of the recovered parts and material decides about the capital investments and the amount of the total costs that the entities can bear. Revenues are also other revenues not related to the sales of the recovered waste i.e. subsidies. Subsidies disturb the market mechanisms but are very often necessary to encourage the enterprises to start and continue an activity in waste recovery.
- Maximization of profitability – this criterion includes the revenues from the activity and the total costs of the activity, hence it is the most complex economic criterion of the network evaluation.

Environmental criteria:

- Maximization of the extent of waste recovery – measured either with the amount of waste supplied to the network or the recycling and recovery rate. This function can also be an indicator of the evaluation of the service quality but, first of all, its maximization denotes a reduced number of waste sent to the disposal sites.
- Maximization of the amount of waste processed – may constitute an objective function when we assume that part of the waste may remain outside the system and in such a situation we should direct the greatest possible waste flow to the recycling network.
- Minimization of the negative impact of the waste disposal – includes not only the negative impact of the waste on the environment but also the negative impact of the waste recovery related activities including its transport.
- Minimization of risk related to the transport of the waste – this is based on the implementation of the proximity principle according to which waste should be transported to the nearest processing entities, which eliminates risks of accidents during transport and, on the local scale, ensures infrastructure necessary for the waste recovery.

Quality evaluation criteria:

- Minimization of the process time – in the case of a large stream of waste the criterion of process time may turn out useful but this criterion cannot be used as the only one in the optimization of the recycling network entity location. This criterion can be used as one of the partial criteria in multicriteria optimization tasks.
- Maximization of process reliability – the process reliability may be interpreted as achieving effect of a certain quality e.g. a given recovery rate. Maximization of the reliability level may be performed at given or limited resources that can be used at the dismantlers or processing stations. Similar to criterion of the minimum process time the maximization of process reliability cannot be the only criterion in reverse logistics network entity location.

5. CONCLUSIONS

It is not possible to classify above criteria from most important to least important because their importance depends on the preferences of a decision maker. Economic operators tend to use economic criteria as a decisive in network modelling while public administration often imposes environmental criteria as key factors in waste reverse logistics network organization. If the points of view of many stakeholders must be taken into account, the best solution is to use multi criteria models that assume the minimization/maximization of the objective function composed of many partial criteria. Each of these criteria reflects often contradictory preferences of the stakeholders.

The most frequently used objective function in reverse logistics, including the building of recycling networks, is minimization of costs. The function of profit maximization is much less frequently used. This partly results from the fact that the organization of a recycling network is perceived in the categories of minimization of the environmental impact at the lowest possible financial burden; it is not supposed to be a profit-oriented activity. We need to remember however that the recycling network will evolve best if the operations in this sector are profitable. Market solutions always bring better effects than legally imposed obligations.

A very important group of sustainable development related criterions should be the environmental criteria. Yet, environmental aspects are most often seen as modelling constraints not objective functions. The applicable laws in waste recovery impose certain recovery rates of end-of-life products that, in network modelling, are treated as requirements that must be met by the network. Increasing of the recovery rate generates greater costs of the activity and the economic criteria are treated as more important from the point of view of the network operation. It is still worth including these criteria as partial ones in multicriteria tasks.

In the building of a waste reverse logistics network the criterion of process time minimization is used even less frequently. Due to relatively little supply of end-of-life products the recovery process time is not a bottleneck in the network functioning and the economic criteria of the conducted activity are more important.

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