The improvement in collection of municipal waste on the example of a chosen municipality

Michał Jakubiak*a

*aWroclaw University of Economics, Komandorska 118/120, Wroclaw 53-345, Poland

Abstract

Ecologistics is the concept which in Poland is not commonly known and is defined differently. The new Waste Act which entered into force in 2013, rose interests in logistics aspects which improve municipality management. Despite many positive aspects which are the result of the new regulations, there is still a lot of chaos and lack of arrangement. Companies and municipalities started to calculate costs which turned out to be much higher than it had been expected. That is why the issues concerning proper management and effectiveness of waste collection are of key importance. Waste management became one of the most important aspects of municipality management, which is very often not only evaluated by scientists, but first and foremost by citizens. The author made an attempt to examine the optimization potential in terms of waste disposal management in Kraków municipality. Improvement in route planning influenced the rise in effectiveness of the performed processes, at the same time lowering the costs of the waste disposal system management. Shortening the time of transport operations caused an increase in transportation fleet availability and possibility to make use of it in the other parts of the city. The study was based on analyzing four routes of municipal waste collection carried out by a disposal company for the Municipal Cleaning Service in Kraków on 4 different days.

* Corresponding author e-mail address: michal.jakubiak@ue.wroc.pl
1. Introduction

In logistics and supply chain, the foregoing solutions focused on the materials flow, their process and manufacturing and delivering the final product to the client in the first place. The interests of researchers and practitioners were only limited to creation processes using the resources and energy offered by the Earth.

Rising costs of energy and natural resources, which are more and more exploited, redefined the existing approach to the traditional concepts of supply chains. There was a search for new methods which could help to recycle some parts of materials which had already been used by humans. As a result, the ecological approach became tantamount to the economical one.

From the beginning of humanity, waste appeared wherever people settled. At first, in fairly small settlements, it was not a problem, just a natural part of every society’s life. Nevertheless, along with the economic development and population growth, waste became a real problem for humankind. The traditional and always present organic waste is now accompanied by a bigger group of new kinds of waste, such as glass, metals, plastics, chemicals, electronic waste, etc. Consumer goods, which are available for everyone, are much more varied and wrapped. People buy more, which is tantamount to the growing amount of waste they throw away. The ecological awareness of the society is also raised. People are aware of the threat connected with the wrong waste disposal and its management.

According to the Waste Act (Act on waste of 14th December 2012, Journal of Laws of 2013, item 21), waste is “every substance or object which the proprietor intends to dispose of, disposes of, or is obliged to dispose of”. In other words, waste stands for all byproducts created by people in their activities (industrial, economic, service), useless in the time and space they were created, harmful to the environment and that could lead to its degradation. In industrial processes, products (finished products) which are desired are created along with products which are unwanted. But does that mean those products are completely useless? For one something can be waste, but for others – in other time and place – it can be a useful raw material, a semi-finished product or even a product. As a result of the fact that the Earth’s natural resources are diminishing, bigger production, and rising costs of energy, waste has started to play a greater part in creating value in supply chains.


In the literature of the subject, two main concepts of secondary logistics are defined:

- reverse logistics – explained as logistics of utilization and recycling,
- green logistics – called ecologistics (Michniewska K., 2006).

Despite the fact that the concept of secondary logistics is of significant importance, the concept has not been unambiguously defined yet. Many authors: Fleischman M. (2000), Mason S. (2002), Kivinen P. (2002) claim that because of the wide range of logistics concept implications used in ecology, it will be difficult to reach a consensus while defining this concept. In order to present different approaches to logistics, a few publications are worth mentioning.

Historically, academia began noticing reverse product and material flows as they surfaced in the 1970s (Peterson, 2005). But it was not until the early nineties that the Council of Logistics Management (CLM) published one of the first definitions of Reverse logistics (Stock, 1992, Marisa P. de Brito, Rommert Dekker, 2002).

“…the term often used to refer to the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal.”

The definition stresses the importance of creating added value from recycling thanks to the possibility of using the materials again and waste management to reduce its nuisance for environment. The role of Reverse logistics in the process of wrapping management and the reduction of its arduousness for people underlines the definition presented by Kroon and Vrijens (1995), in which Reverse logistics refers to the logistics management skills and activities involved in reducing, managing and disposing of hazardous or non-hazardous waste from packaging and products. Pohlen and Farris (1992) define Reverse logistics guide by marketing principles and by giving it a direction insight, as follows: “…the movement of goods from a customer towards a producer in a channel of distribution.” Kopicky (1993) defines Reverse logistics analogously to Stock (1992), but keeps, as previously
introduced by Pohlen and Farris (1992), the sense of direction opposed to the traditional distribution flows: “Reverse logistics is a broad term referring to the logistics management and disposing of hazardous or non-hazardous waste from packaging and products. It includes reverse distribution (...) which causes goods and information to flow in the opposite direction of normal logistics activities.”

Dale S., Rogers Ronald S., Tibben-Lembke (1998) claim that definition of Reverse logistics should stress management aspects above all. “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 for proper disposal.”

A similar idea is expressed by the European Working Group on Reverse logistics, RevLog (1998-). They put forward the following definition: “The process of planning, implementing and controlling flows of raw materials, in process inventory, and finished goods, from a manufacturing, distribution or use point to a point of recovery or point of proper disposal.” Ph. Schary i T. Skjott-Larsen (2002) present an idea in which “Reverse logistics is a separate task in a demand chain, for which its own environment should be created – waste chains. In spite of different environment, logistics of waste collection is tightly connected with the traditional supply chain and it participates in creating the value of final products.

The second name often used for describing logistics in ecological problems is Green logistics, Ecologistics. The concept of Green logistics was born in 1987 with the World Commission on Environment and Development report of 1987. In the Polish literature studies a lot of authors consider Green logistics as the concept in which the main stress is put on reducing the negative effect of waste on the environment and search for optimal logistics solutions in this respect (Słowiński B., 2008). Such solutions and activities include: designing wrappings with minimal material input, the use of transport solutions to reduce pollution, packaging recycling. In this example, ecologistics is more preventive, whereas reverse logistics is oriented to manage situations which happened and/or to reduce the negative impact of human activities.

Rogers and Tibben Lembke and Steele and Rodriguez studied the relationship between green logistics and reverse logistics. Today, Green logistics is very often defined as “supply chain management practices and strategies that reduce the environmental and energy footprint of freight distribution” (Steele, K., & Rodriguez, E., 2008).

Recycling, remanufacturing and reusable packaging are the areas where reverse logistics and green logistics intersect (Peterson, 2005, p. 9). “While reverse logistics will examine how waste is disposed reducing landfill waste, the focus in reverse logistics is the cost and availability of landfill space, rather than conducting specific studies on the organizations environmental impacts. The drivers for reducing waste in reverse logistics are associated with increased regulation, increased landfill costs, or economic benefits of using fewer raw materials” (Rogers and Tibben Lembke, 1998, pp. 101 – 112).

“A reverse logistics process can take many different forms and has many different possible opportunities to manage the product and re-introduce it to the supply chain. In reverse logistics consideration is given to the collection and transport of returns. One the return is received, there are many areas where the product may move such as testing, refurbishment re-use of parts, od recycling back to raw material. A greening process is simplistic in that it begins at the source with supplier conditions and can work its way through manufacturing, packaging, and distribution channels” (Nylund, 2012, pp. 51-52).

3. Problem presentation and research goal

In Europe waste is more and more often used to produce materials and energy. What is more, recycling became a modern method to obtain materials and use them to create new products. What was successful in a lot of countries of western Europe, it is now being implemented in Poland. The Waste Act which entered into force in July 2013 completely redefined the system of waste management. It obligates local authorities to apply selective municipal waste collection and imposes on municipalities a lot of new duties, such as covering costs of:
• reception, transport, collection, recycling, and reduction of the negative effect of waste,
• creation and maintenance of municipal selective waste collection points,
• administrative system service,
• other services (educational role).
Municipal Cleaning Service in Kraków is a company which has existed on the market since 1906. In 1993 it became a limited liability company where 100% shares are owned by the Municipality. The new regulations, introduced nationwide, made Kraków Municipality take responsibility for the system of cleaning and maintenance in the administrative borders of the whole city. On 11th July 2013, the Local Council imposed the following duties on MCS:

a) managing the system of municipal waste collection and maintenance
b) maintaining order and cleanliness on public roads
c) operation of a facility to utilize municipal waste, and of Points of Selective Municipal Waste Collection.

In order to fulfill the abovementioned duties, Municipal Cleaning Service in Kraków, based on a competitive tender, chose three companies to carry out the disposal and collection of waste. Kraków Municipality, making the MCS responsible for the system of waste management, also obliged the company to have control over the municipal waste management, as well as supervision of ordered tasks carried out by entities which collect municipal waste from property administrators (Hanczar P., Pisiewicz D., 2015).

Inspections ordered by MCS found a lot of flaws in the processes of waste collection carried out by disposal companies. They mainly concerned not keeping due dates of waste collection and lack of predictability and clarity of routes covered. Residents and administrators of properties are provided with a fixed schedule of waste collection, as a result, any changes in the dates and times are reported as flaws in the system. It was also observed that routes covered by disposal companies, despite a lot of control mechanisms such as satnav. readings, were difficult to verify (Fig. 1). The inspection showed that many a time drivers were in a different place than the one specified in the schedule. There was also no consistent planning system which could prompt to which location the waste collecting team should go in the first place. The lack of planning process caused the situation where a driver could decide at his full discretion which routes to choose. This could result in malpractice and taking additional jobs which are not in the contract signed with Municipal Cleaning Service in Kraków.

Fig. 1. Readings from satnav, installed in a lorry of a company carrying out the process of waste disposal
Source: based on data provided by MCS in Kraków
The goal of the analysis was to determine the optimization potential, to indicate the benefits of introduced changes, and to specify the constraints which can influence the use of optimization tools.

4. Model

In this research study, the assumed optimization criterion was to minimize the distance covered by the truck collecting waste from a single-family housing area on chosen days of the week.

The basic group of problem solution methods includes TSP (Travelling Salesman Problem) which is an application of the classical branch and bound method, which was elaborated by Little et al. (1963).

Despite the fact that at this stage of the research there was no need to include additional constraints, other than the ones included in classical TSP tasks, the author suggested two approaches. One of them includes a very common constraint which is faced by disposal companies, such as time periods in which waste collection can be carried out.

Because of future requirements, such as time windows, the first model was presented by formulas (1) to (6). This approach makes use of two decisive variables. The first of them is \( x_{ij} \) which equals to 1 if the line \( i, j \) is in the solution. The second variable is \( s_i \) which stands for the time of arrival at point \( i \). Symbol \( V \) stands for the set of all hubs, whereas \( A \) stands for the set of connections on it. In addition, following parameters were used: \( c_{ij} \) stands for the length of \( i,j \) connection; \( t_{ij} \) stands for the time of ride between \( (i,j) \); \( R_i \) – beginning of time window for \( j \) point; \( D_j \) – the end of time window for \( j \) point; \( M_{ij} \) – any big plus value (however, to speed up the solution, this value should be set as \( M_{ij} = D_i - R_j + t_{ij} \)).

\[
\min \sum_{(i,j) \in A} c_{ij}x_{ij} \quad (1)
\]

\[
\sum_{j \in V} x_{ij} = 1 \quad \text{for every } i \in V \quad (2)
\]

\[
\sum_{i \in V} x_{ij} = 1 \quad \text{for every } j \in V \quad (3)
\]

\[
s_i + t_{ij} - (1 - x_{ij})M_{ij} \leq s_j \quad \text{for every } (i, j \neq 1) \in A \quad (4)
\]

\[
R_i \leq s_i \leq D_i \quad \text{for every } j \in V \quad (5)
\]

\[
x_{ij} \in \{0,1\} \quad \text{for every } (i,j) \in A \quad (6)
\]

\[
s_i \geq 0 \quad \text{for every } i \in V \quad (7)
\]

Constraints (2) and (3) are to ensure that the vehicle goes through every point. The most important thing is to formulate constraint (4) which on one hand can ensure the continuity of the route, and on the other is to guarantee the coherence of changed variable \( s_i \), that is after visiting the \( i \) point, \( j \) point is visited, \( s_j \) must be greater than \( s_i \) with the value of driving time between these points. Another constraint (5) is to ensure that every point will be visited in a given time window. The last two constraints (6) and (7) are margin constraints. The first formula, in accepted time, allowed to solve the task for about 30 points. That is why this approach will be used only when the data of location to visit are aggregated. Nevertheless, in the case of bigger tasks there is a necessity to use approximate algorithm.

As the second algorithm, a classical 2-optimal method was used. The operation of this method is based on the iterative improvement of the acceptable solution. In the classical version of this method, in one iteration the route is modified by exchange of two lines for two new ones. However, the exchange is only accepted when it leads to
shortening the route. Calculation complexity of 2-optimal method is constrained by polynomial of second degree, that is $O(n^2)$. This algorithm does not enable to include time windows. Yet, this requirement was not needed in the analyzed example that is why in the research a very fast 2-optimal method was used. For this method the system can find solutions in current time.

5. Results of the research

One working week (consisting of 4 days) of team no. 2, between the 6th and 10th July 2015 was examined in the research. The distance of routes covered by the team disposing of municipal waste was analyzed. The same routes are covered every two weeks as the Company, following the yearly schedule of municipal waste disposal. For the residents of single-family houses the disposal takes place once in two weeks.

In the first step (Variant I), the route, sent by the planner, was calculated. This variant is a list of locations, in the alphabetical order that the team has to visit. In this case it is difficult to describe it as a plan, it is just some list of locations.

The second research variant is an attempt to reflect the real route carried out by team no. 2 on the following days: 06.07.2015, 07.07.2015, 08.07.2015, 09.07.2015. The obtained result is marking the location of houses which are the result of satnav’s indications order. The distance and driving time calculations are done using an ICT tool which connects with google maps.

The last stage of the analysis is route optimization by means of an ICT tool created by the author. The average truck speed is 9 km/h and 45 seconds to service a single collection point were assumed in the research – the parameters are the result of satnav readings analysis for a few disposal teams.

Length of the route is a basic optimization criterion. Depending on the needs determined in further research, the criterion can be modified. While using an optimization mechanism, a simplification, which presumes the aggregation of points on the route, was assumed. Originally, the route covered by team 2 (Monday) had 291 points of collection. In order to reduce the number of calculation operations, it was assumed that that two the furthest numbers in the street are included in the optimization, which in this case will require from the driver to visit all locations.

If team no. 2 on the 6th July 2015 (Monday) did the job according to the plan presented in the order, the length of the route would equal to 33 km. The approximate time of driving, along with waste collection (not including unplanned stops or other traffic holdbacks) is 7 h 18 min.

<table>
<thead>
<tr>
<th>Day/route</th>
<th>Variant I (variant sent by the planner)</th>
<th>Variant II (actual route – SatNav readings)</th>
<th>Variant III (optimization suggested by the author)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>distance</td>
<td>time</td>
<td>distance</td>
</tr>
<tr>
<td>06.07.2015</td>
<td>33.0 km</td>
<td>7 h 18 min</td>
<td>27.5 km</td>
</tr>
<tr>
<td>07.07.2015</td>
<td>48.0 km</td>
<td>9 h 02 min</td>
<td>38.0 km</td>
</tr>
<tr>
<td>08.07.2015</td>
<td>89.0 km</td>
<td>13 h 34 min</td>
<td>39.0 km</td>
</tr>
<tr>
<td>09.07.2015</td>
<td>106.0 km</td>
<td>15 h 16 min</td>
<td>47.0 km</td>
</tr>
</tbody>
</table>

Source: own elaboration

Calculating the distance of the route following real SatNav readings, it can be observed that the team which covers the route moves according to its own experience and it does not follow indications sent by the planner. Thanks to this, real distance on 06.07.2015 was 27.5 km.

<table>
<thead>
<tr>
<th>Working day/</th>
<th>The best solution (Variant III)</th>
<th>The decrease in real time of execution (variant II) with reference to the best solution (in %)</th>
<th>Sent plan worsening (variant III) with reference to the best solution (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06.07.2015</td>
<td>-</td>
<td>25.00</td>
<td>50.00</td>
</tr>
<tr>
<td>07.07.2015</td>
<td>-</td>
<td>15.15</td>
<td>45.45</td>
</tr>
<tr>
<td>08.07.2015</td>
<td>-</td>
<td>18.18</td>
<td>169.69</td>
</tr>
<tr>
<td>09.07.2015</td>
<td>-</td>
<td>11.90</td>
<td>152.38</td>
</tr>
</tbody>
</table>

Source: own elaboration

After the implementation of the optimization mechanism, the route distance was decreased to 22 km and the
estimated ride time equaled to 6h 4 min (not including any unplanned stops or other traffic holdbacks). Similar trends can be observed during next working days of team 2 (see Table 1 and Table 2).

Fig. 2 Comparison of the routes a) route covered by team 2 on 08.07.2015, b) route suggested by the author

Some significant differences can be observed between the “pseudo” plan sent by the planner and the real execution. They could even amount to several dozen percent of route worsening with reference to the best solution. Big difference can be observed between the real plan execution and the solution suggested by the author.

6. Summary

The analysis showed that implementing some simple optimization methods allows to significantly shorten the distance of municipal waste collection routes. Further research focuses on identifying the constraints which could
influence the optimization mechanism. It is essential to thoroughly analyze the so-called time windows that is times of day at which waste collection should take place for given locations. The model presented by the author takes time windows into account. However, in reality it was difficult for the company, at that stage of research, to indicate those windows. The plan, shown to the drivers, allows to control the work in a better way, as it is enables us to determine in which location the workers should be in a chosen period of time. The discretion left to the workers by the planner in the plan execution and route covering cause some serious deviations in the real time of driving compared to the optimal solution. Leaving the route planning to the driver can cause numerous defects such as adding points which should not be counted in a given ride.

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