MUNICIPAL WASTE COMPONENTS AND THEIR COLLECTION BY COMPUTER SUPPORT

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Growing volumes of different waste types produced by industrial companies represent a serious threat for the environment. Unthoughtful waste liquidation by means of dumping results to massive valuable resources wasting on one hand and in environment pollution by greenhouse gases emissions into the air, endangering underground water by extract liquid seepage and soil contamination by heavy metals on the other. The only possible method of a sustainable development is a consistent separation of reusable materials contained in waste and their consequent recycling, separation of combustible waste by means of environment-friendly technologies, by separation of bio-degradable materials suitable for composting with a consequent return into natural nutriment cycle, and last but not least, by separation of hazardous waste components and their ecological /liquidation/use. The article focuses on the options of operational research methods in combustible waste management, handling separated bio-degradable municipal waste components and hazardous waste management in the Pardubice Region.

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Key words: municipal waste, combustible waste, bio-degradable waste, hazardous waste, computer-aided decision making, operational research, theory of graphs, location analysis

1 Introduction

Numerous decision-making processes in regional self-administration have an essential impact on a given region's environment. Among the most significant and distressing problems especially in the period of world economic recession lists waste management, especially the ways of handling municipal waste, hazardous waste, biological-origin waste, terminated service life cars, accident wrecks etc. While the waste management and recycling development up to mid-2008 appeared to be quite positive, current situation is alarming. The interest in certain separated commodities has declined raw materials purchase prices have fallen down and particular waste collection must be paid. Therefore the already launched waste management systems need re- assessment and new options must be sought for.

Recent discussions in the Czech Republic aim at the suitability and waste utilization in power engineering. Combustible waste in centralized regional incineration plants meets with a great resistance of local inhabitants in the plants vicinity. Besides the dust and emissions burden, the centralized waste incineration model presents an increased cost for waste collection and loading roads with the collecting vehicles. Alternative of combustion in centralized incineration plants is represented by local plants facing the problem of sufficient use of their capacity.

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Surveys of waste composition show the growth of biological-origin waste [1]. This is why the main attention is paid to separate collection, i.e. the separation and use of the bio-degradable waste component by means of composting. The waste structure differs according to the type of built-up area, the way of heating etc. In the case that a municipality is connected to gas distribution, then the average contents of collecting vessels (dustbins) significantly differ from the contents of the vessels filled in gas-supplies-free municipalities.

Vast majority of Czech municipalities separate the municipal waste components; most of them separate plastics, paper, glass, and oversize and hazardous waste collection is carried twice a year at a minimum.

Common household waste is cumulated and removed regularly all year round and dumped or classified in separation yards. Specially equipped vehicles are used for the collection of hazardous, metal and oversize waste.

Main attention of the Pardubice Region self-administration authority in term of waste management has recently been paid to the following three areas: options of municipal waste or its separated parts combustion; separated collection of bio-degradable and hazardous waste.

In the case of combustion waste or its parts, there has been a public discussion concerning the problem of combustion or not combustion the waste, and if the answer is positive, then it is important to decide, where to burn. Separation of hazardous waste has been run for several years already, and bio-degradable waste has been separated for three years.

2 Analysis of Waste Composition and Production

The results of latest analysis of municipal waste composition in the Czech Republic show a significant proportion of mixed household waste in the total volume of municipal waste that makes 65–80 % [1]. Specific amount of mixed waste was measured in 4 built-up area types, according to the number of inhabitants and the prevailing way of household heating. Average amount of household waste moves between 2.41–3.50 kg per capita and week excluding the re-usable components separated collection (paper, glass, plastics). Overall specific household waste production moves within 2.50–3.80 kg per capita and week.

Table 1 shows the waste composition percentage depending on the built-up area type. The research was carried out in large residential districts of major cities, residential districts of minor cities, in mixed municipal and rural residential districts and in the countryside. While the three monitored urban areas the percentage proportion appear comparable, the composition of rural waste is significantly different. This relates especially to the option of burning a part of waste and bio-degradable waste composting, and last but not least, a part of organic/vegetal origin is used as domestic animals food.

Mixed municipal waste production has recently shown a slight growth by average 2–3 % of weight per capita and year. Especially the share of plastics has been growing, as well as paper consumption. Other waste components show an opposite trend, e.g. ashes where the proportion has been falling down due to the change in the way of the heating by a transfer to fine fuels. The growth in fine fuels proportion is also influenced by gas installation in numerous municipalities and central heating plants boiler rooms reconstruction in residential districts.

Table 1 Municipal waste composition according to built-up area type

Waste	Average values (%) according to built-up areas			
	>80000	**<=80000**	**Mixed**	**Village**
Paper	18.1	20.8	26.2	5.5
Plastics	14.1	16.8	17.1	7.7
Glass	8.5	5.8	6.7	5.3
Metals	3.6	3.1	3.2	4.8
Bio	19.6	20.4	17.6	6.9
Textile	6.0	6.9	5.2	2.4
Mineral	2.0	0.8	2.4	4.3
Hazardous	0.6	1.1	0.4	0.5
Combustible	13.4	7.0	7.2	6.8
20–40 mm	3.7	8.9	5.6	5.8
8–20 mm	7.1	5.3	3.9	9.7
< 8 mm	3.3	3.1	4.5	40.3
Total	100.0	100.0	100.0	100.0

Source: Project VaV 720/2/00 – Intensification of collection, transport and classification of municipal waste.

Table 2 Average waste production in CZ

Average production of municipal waste	Max 300–350 kg/person/year
Average production of household waste	Max 150–200 kg/person/year
Average production of usable household waste components (paper, plastic, glass, metals)	60–85 kg/person/year
Average production of hazardous waste	0.5–2 kg/person/year
Hazardous waste including products	4.5–6 kg
Average production of oversize waste	40–60 kg/ person/year
Average production of compostable waste	20–30 kg/ person/year
Average production of street sweep	10–15 kg/ person/year
Average production of manufacture waste	60–120 kg/ person/year

Source: Project VaV 720/2/00 – Intensification of collection, transport and classification of municipal waste.

2.1 Combustible Waste

While combusting major part of household waste at individual heating units is banned by the law, combustion in central incineration plants is permitted. Combustible waste concentration and burning in corresponding technology equipped incineration plants provides energy-generating use of the waste and environmental friendly liquidation of large waste amounts. There exist three scenarios for combustible waste handling:

- combustion in individual heating units,
- combustion in low-volume local/municipal incineration plants,
- combusting in regional incineration plants.

Each of the above listed scenarios has its positive and negative impact. If household waste is wood material or paper, the combustion at the place of its origin is not a hindrance since it does not represent an extra load for the environment. In addition, it is not required to concentrate, sort and further manipulate the waste, which reduces the waste management logistic cost. This way of liquidation is certainly suitable only in the places lacking the gas supplies, i.e. at households burning classical fossil fuels and wood.

The system of burning in local low-volume incineration plants is more effective and, in terms of environment protection, a more friendly way of burning. Another advantage is the distance between the place of the waste/resources origin and the incineration plant. The cost of waste collection is lower compared with the collection within the regional incineration plants system. Even in this case one can say that the waste is disposed of at the place of its origin. A certain drawback of the system relates to the use incineration plants capacity. On one hand, a limited territory assumes an unbalanced waste generation resulting in uneven incineration plant operation due to the lack of resources and on the other hand, at certain times the combustible waste collection tanks may well be overloaded.

The third system is designed for operation in regions that run solid fuel heating plants and power plants of a sufficient capacity. The system seems to be the most suitable in terms of an individual user as well as in a broader perspective (minimizing of dumps number, regular waste collection etc.). Concentration of combustible material is sufficient and inequalities and seasonal character of waste generation throughout the year is up to a certain extent balanced by the acreage of the concerned area. The concentration makes the whole process economic-transparent and effective. A certain disadvantage is a high logistic cost for the collection management.

The above listed positive/negative aspects of the feasible municipal waste combustion scenarios belong to the category of hypothetic arguments. The question of individual systems suitability will eventually be selected within the decisive powers of regional self-administration authorities and the will of the residents. Selection of the scenario will significantly influence the development of logistic system of municipal waste collection and liquidation.

2.2 Biodegradable Waste

The definition of bio-degradable waste in the Czech Republic is determined by Act 185/2001 Sb., on waste. Bio-degradable waste is considered any waste subject to aerobic or anaerobic decomposition.

The Directive of the European Parliament and Council of Europe (ES) 98/2008 provides a more detailed definition of bio-degradable waste: bio-degradable waste is formed by all biologically degradable waste of gardens and parks, food and kitchen household waste, restaurants, catering and retail facilities and comparable waste of foodstuff industry facilities. Bio-degradable waste does not include forestry and agriculture waste such as cleaning plant sludge or other bio-degradable waste (e.g. textiles, paper or processed wood).

The problems of bio-degradable waste in the Czech Republic recently present an important issue. It has been discussed in terms of environment protection and in regard to economic aspects. The need to separate bio-degradable municipal waste components must be assessed with regard to the recent studies that record a significant worldwide decrease of organic matter in soil in relation to intensive agriculture processes.

To maintain a natural nutrient cycle it is essential to return these matters to the soil. Separated bio-degradable waste collection or its separation from municipal waste may present a meaningful solution. The problem of bio-degradable waste in the Czech Republic concerns all built-up area types including rural areas.

Composting present the most frequently used method of returning organic substances into soil. Humus generated by composting increases the soil retention and decreases the risk of floods. Czech legislation stipulates reduced biological waste dumping. Second option to composting is energetic biomass revaluation in biogas plants for electric energy production. The municipal waste composition analyses show that the share of bio-degradable waste in certain parts of the Czech Republic exceeds 40% [1].

Latest developments support the assumption that the proportion of unsorted bio-degradable waste will decline in the following years. Reduction of dumped bio-degradable waste proportion is determined by the Directive of the Council of Europe 1999/31/ES.

Collection of bio-degradable waste in Pardubice is carried out by the company SmP – Waste Corp that provides municipal waste collection in the whole city. Bio-degradable waste is recently separated in three selected city districts and then delivered to the only municipal composting plant in Dražkovice. Composting is based on the aerobic waste decomposition technology.

2.3 Hazardous Waste

Residents of Pardubice may dispose of hazardous waste in 8 waste collection yards throughout the year. The yards management stipulates the conditions for the collection and types of collected waste. The service is free. Every citizen has the right to dispose of 200 kg waste per a week. The service is not designed for industrial waste collection. A special transfer point subject to payment is used for industrial waste collection.

To make the hazardous waste collection service more friendly and effective for the citizens, the SmP – Waste company organizes four times a year a collection carried out by means of specially equipped collection vehicles. The collection is carried out in the form of city cruises collecting hazardous waste from the citizens at determined points and times in 8 cycles covering the whole territory of the city of Pardubice and neighbouring villages. Among the collected waste list especially car-operation waste, light resources, batteries, photo-chemicals, paint materials, plant protection chemicals, other chemicals, greases, oils, hazardous waste containing home appliances, healthcare material and detergents. Assorted waste is delivered for recycling or liquidated by burning under high temperature in certified incineration plants.

3 Problem Formulation

3.1 Combustible waste

If we include paper, plastics, textile, cork and other materials into combustible waste, the combustibles represent an important part of municipal waste. In association with biodegradable and hazardous waste, the combustible waste in all 3 types of urban fabric patterns gives on average of 73.2 % of the total weight of the waste, 31.8 % in rural areas [1].

Consistent separation, energetic recovery of combustible waste in the form of combustion steam or conversion into electric energy and composting of biodegradable waste allows a substantial decrease in the waste amount to be stored at landfills. Recycling and ecological removing of hazardous waste decreases the risk of groundwater contamination by leach ate.

Separation of partial municipal waste components and its handling requires the building of specific logistic systems requiring numerous key decisions. As far as combustible waste is concerned, we have to deal with the following problems:

- selection of local or central combustion,
- number of incinerators and their location,
- number and location of separation devices,
- technology of convenient municipal waste components suitable for combustion in incinerators,
- waste collection route planning,
- location of landfill yards,
- modes of utilization of heat energy from the combustion process,
- energy distribution mode.

3.2 Biodegradable waste

In the event of municipal solid waste organic fraction with the exception of rubber, plastic and leather components, it is essential to address the following problems:

- choice of container type for separate collection,
- location of composting facilities,
- composting techniques,
- collection systems design,
- compost recovery,
- mode of separation and handling of inconvenient biodegradable waste ingredients.

Besides the publicity, the effectiveness of hazardous wastes collection by specialised vehicles is also influenced by:

- convenience of truck collection sites locations,
- convenience of collection routes and timetable.

The growth of municipal waste amounts, urban expansion and increasing of partial municipal waste components collection causes that manual planning of the collections routes becomes a difficult task whose solution significantly influences the logistic systems effectiveness.

Similarity of the problems to be solved when designing the appropriate logistic system leads to the use of operational research methods, especially the Location Analysis, the Theory of Graphs and Linear Programming.

One of the most important tasks is the determination of optimal collection truck routes that influence logistic system effectiveness most of all.

Collecting routes for commingled municipal wastes, separately collected biodegradable waste and hazardous waste are designed by the vehicle fleet dispatcher. The method used for the collecting routes lay out is heuristic based on the dispatcher's knowledge, intuition, operating experience and historical data. If done manually, the collection routes lay out is a difficult task especially in large urban areas. It has been proved that manually designed collection routes were almost better than those designed by automated tour-building programme codes [3]. There is also scepticism against automatically designed routing. It is understandable especially due to the fact that is not always possible to involve into the model all the constraints and conditions.

The need of a proper decision making, rationalization, optimization and automation in the collecting routes lay out assumes the design of a planning tool based on a computer programme that would enable:

- support for dispatcher's decision making,
- the first stage collecting routes lay out, respecting the basic conditions and criteria,
- interactive construction of collection routes,
- simulator for stuff training,
- statistical tool for the collection system effectiveness evaluation etc.

The tool would include the options of intelligent transportation systems such as GPS collection vehicles tracking, operative changes of the collection routes etc.

4 Problem Solution

As mentioned above, the most complex problem of a dispatcher's apparatus in municipal or private firms that provide solid waste collection is lay out of optimal collection routes in municipal network.

The main criterion for the collecting routes planning is the total amount of kilometres travelled by the collecting vehicles. A minimum amount of the travelled kilometres equals to the sum of partial sections of streets included into the appropriate loop.

In real situations is not usual that a single collection route includes every section only once; some of the sections must be passed often more times in order to serve all the sections in the concerned district. Multiple travels through the sections present an inefficient performance; therefore it is necessary to plan all the fleet vehicles routes to minimize the amount of inefficient kilometres.

Efficient collection routes planning relates to the theoretical works of Leonard Euler who generalised two conditions to be fulfilled for any network so that it would be possible to traverse the whole collecting route without passing any road or road section more times [3][5].

Road network is expressed in the form of a non-directed graph consisting of nodes (intersections) and evaluated edges (section of roads).

There are two possible shapes of the Euler path: closed and opened tours. A closed path (Eulerian circuit) begins and finishes at the same node. The open path begins and finishes at different nodes. The condition for closed path existence assumes that all the nodes must be of even degree. It means that all the nodes must be incident with even number of edges. These graphs are denoted as Eulerian graphs ore unicursal graphs.

An open path graph must contain only two nodes of an uneven degree while all the other nodes are of an even degree. A common condition for both closed and open paths is the graph connectivity.

As real municipal road systems are concerned, we must take into account the existence of both one-way and two-way streets. In addition, there exist dead end streets and streets with other restrictions so that the graph representing the communication system is usually not an Eulerian graph.

One-way streets must be in accord with the Euler's theory. The degree of each node express number of possibilities to get to the node, as well as the number of the node outlets. The number of entrance possibilities must equal the number of outlets. Unless all the nodes comply with this condition, fictive edges must be added to the graph so that it becomes en Eulerian graph. Fictive edges are to be added between the nodes of an odd degree. They represent the shortest path between relevant nodes of odd degree in the original graph. In a graph completed by fictive edges, there exists an option to construct a closed Eulerian path. When substituting fictive edges by the appropriate shortest path, we obtain the shortest route minimizing the sum of the travelled distance.

5 Collecting Routes Design

Several ways exist for closed/open Eulerian paths construction depending on the manner of selection of the successive edges included into the path. Theoretical method for an Eulerian path construction was designed by Fleury in 1883, known as Fleury's algorithm.

The problem was also dealt with by a Chinese mathematician Mei-Ku Kwan who designed an effective method for a unicursal network construction. The problem is known as the Chinese Postman Problem.

A modified algorithm is to be used when the graph of the network is not of Eulerian type, but includes two odd degree nodes. The modification consists of a fictive edge addition to the graph between the odd degree nodes. We obtain an Eulerian graph in which construction of closed Eulerian path is possible. One of odd degree nodes must be selected as a starting node. As the first edge to be passed the fictive edge is used. After finishing the construction the fictive edge is deleted from the path and open Eulerian path is obtained beginning in one and finishing in the second odd degree node.

In graphs containing greater number of odd degree nodes than two a route of minimal length is defined. The route of minimal length between the starting and ending node is defined as a sequence of the nodes and edges where nodes can repeat more than once as well as edges.

A string of minimal length in a graph with weighted edges can be constructed by Edmond's algorithm:

1. determination of odd degree nodes in a graph,
2. construction of a complete graph for nodes with odd degree inserting fictive edges,
3. weighting the fictive edges by the distance of nodes in original graph,
4. determination of optimum branching,
5. insertion of optimum branching edges into the primary graph between the appropriate nodes of the odd degree (we obtain graph in which all nodes are of even degree, multiple edges may occur),
6. in graph resulting from step 5, Eulerian path by Fleury's algorithm is constructed,
7. substitution of fictive edges by the appropriate shortest path,

8. Obtaining a minimum length string.

Dispatchers of municipal or private firms performing the collection of municipal wastes often use different more or less sophisticated heuristics. Several different rules, patterns and recommendations derived from the practice can be taken into account when laying out collecting routes as follows [3]:

- wherever possible, routes should be laid out so that they begin and end near arterial streets,
- in hilly areas, routes should start at the top of the grade and proceed downhill as the collecting vehicle becomes loaded,
- routes should be laid out so that the last container to be collected on the route is located nearest to the disposal site,
- the routes should not overlap, but should be compact and not fragmented,
- the starting point should be as close to the truck garage as possible,
- heavily travelled streets should be avoided during rush hours,
- sources at which extremely large quantities of wastes are generated should be serviced during the first part of the day,
- scattered pickup points (where small quantities of solid wastes are generated) that receive the same collection frequency should, if possible, be served during one trip or on the same day.

The above mentioned rules enable the stakeholders to construct reasonable collection routes minimizing ineffective haulage.

The use of the Eulerian path theory for the collection routes construction is suitable only in the case the streets are densely planted by collection containers as it is in the case of commingled municipal waste.

If the sites of collection containers are deployed sparsely and are scattered in the concerned area, as it is in the case of biodegradable and hazardous waste, we need to use the Hamiltonian circles theory.

In individual tasks we use methods based on the Clark Wright algorithm or the Little's algorithm according to the capacity of the collection vehicle.

6 Conclusion

Need of an automatic tool supporting the decision making in collecting routes planning leads towards design of sophisticated computer models allowing automated collecting routes design.

The designed tools also facilitate the use of intelligent transportation systems for on-line operation. The collection vehicles are equipped by satellite navigation systems allowing a nonstop monitoring of the vehicles position and its comparison with the plan. Operative changes of the planned collecting routes resulting from the real-time state of road systems and traffic are transferred to the collecting vehicle crews by a mobile phone.

The SW also disposes other useful planning tools, such as the calculation of optimal collecting vehicles number, area districting, allocation of the servicing sites etc. It provides also the statistical data, such as the daily volume of waste collected by individual vehicle, by the whole fleet, time schedule completion etc.

This article is a minor contribution to the discussion of solid waste management and its aim is to inform about the approaches to the problem in the Czech Republic, especially in the Pardubice region.

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