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Topic: Waste collection and transport

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Software tool for designing, optimizing and managing household-refuse collection services

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Abstract: Environmental issues related to waste collection are a major concern for both waste management actors and public opinion. Providing a well-organized household-refuse collection service with optimized routes reduces the environmental impact of such an activity and represents a topical challenge.

However, waste collection services providers, engineering and design offices or local authorities still design waste collection districts and routes by hand, sometimes with the aid of sophisticated geographical information systems (GIS) for easier visualization. Many constraints have to be taken into account (single/double side collection, turns, priorities, time windows for specific addresses, travel cost model…), which are often too complex or too numerous for a human mind to grasp. Consequently, the resulting districts and routes are usually reasonable, but not always optimized in terms of travelled distance, let alone energy consumed or gas emitted.

Although there are many vehicle routing software on the market, very few integrate a comprehensive knowledge base of data and business rules specific to the waste management activity.

Therefore, MASA Group has developed BlueKaizen Residential Waste™ from the end-users' perspective, focusing on trade specific rules, constraints, degrees of freedom and criteria. An optimization engine (owned by MASA Group) and a GIS component (from ESRI) were added as supporting tools. The result is a software tool intended for all the actors of the waste management sector.

The paper gives an overview of the investigations carried out with varied operational and technological partners to perform an optimal representation of reality.
A modelling of the collection process is proposed. It is based on specific constraints and uses information on population density, waste generation capacity, storage bins, collection vehicles' characteristics, road networks and types of roads, etc.
The optimization engine coupled with this model is also presented. Arising from years of work with experts, it is based on state-of-the-art algorithms (metaheuristics), which enable to solve real-life waste collection problems. The paper explains how optimization criteria can be defined to favour minimization of distance, working duration or energy consumption.

In accordance with sustainable development, the results obtained are promising from both the economical and ecological point of view. The optimization of human and material resources involved allows reducing significantly pollutants emissions and their impact on climate change in the same time as waste management becomes more cost-effective.

Keywords: modelling, environmental impacts, municipal waste, waste collection, optimization, decision support software

Introduction

The important rise in the urban population in developed countries and the resulting accelerated urbanization phenomenon has brought to light the necessity to develop environmentally sustainable and efficient waste management systems.
An important amount of expenditures is usually spent by public authorities on municipal waste collection. Moreover, both waste management actors and public opinion feel more and more concerned by environmental issues. Therefore, providing a well-organized household-refuse collection service with optimized routes represents a topical challenge.
The general trend aims at reducing the economical and environmental impacts of waste collection activity. Varied methods have been applied in order to improve household-refuse collection services: encouraging people to sort recyclables, using less polluting vehicle, reducing the number of transits by decreasing the collection frequency or favouring multi-flux collection, etc.

Much progress has been made in the field of waste collection. Nevertheless, a lot of work remains to be done as regards to the route collection design and the reduction of involved resources. During the past years, there have been lots of technological advances. Therefore, more and more consideration is being given to computerized decision support tools. Many vehicle routing software are provided on the market but very few integrate a comprehensive knowledge base of data and business rules specific to the waste management activity.

This paper aims at presenting a software tool for designing, optimizing and managing household-refuse collection. Section 2 shortly describes the problematic of the municipal waste collection process. The general approach we used is presented in section 3. Section 4 describes our model of the municipal waste collection process. Section 5 describes the optimization process. A case study with analysis and results is proposed in section 6.

Overview of the current practice

Waste are located along the streets of a defined road network. Varied types of flux have to be collected (organic waste, plastics, glass, paper, etc). Each waste type (flux) is stored in a different container (assuming that sorting of recyclables is done). In case of a multiple-flux collection, several waste types are collected by the same vehicle. Therefore, some vehicles have at least two compartments (each compartment is dedicated to a specific waste type). The capacity of each vehicle (and its compartments) cannot be exceeded.

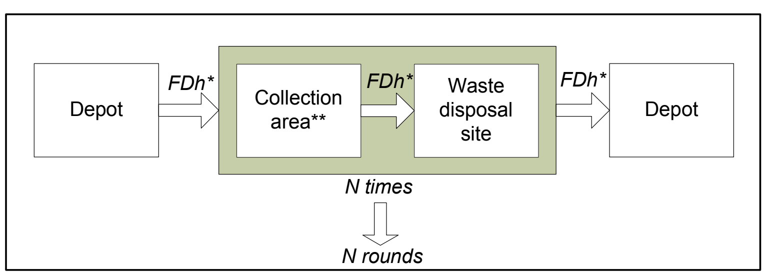
Collection time must occur during specific time slots. Moreover, it has to respect legal work limits of drivers and loaders. Break times have to be taken into account within the schedule. Waste disposal sites are accessible during given opening hours.

The whole collection process performed by a single fleet is called a “route”. Each route can be decomposed into several rounds. At the end of a round, each vehicle is unloaded at a waste disposal site (see Fig.1). Vehicles leave their parking (called “depot”) at the start of the route and return there at the end of it.

Two different routes can be done with the same vehicle on the same day (usually one in the morning and another one in the afternoon with a different fleet). A route contains the alternation of two phases: collection phase and deadheading. During a deadheading, the loaders can be either standing at the rear of the vehicle (“slow deadheading”) or sitting next to the driver (“fast deadheading” or “transportation deadheading”).

Slow deadheadings correspond to all the moves made by the vehicle to go from a collect link to another one (within the collection area). In this case, the speed has to be low in order to respect workers’ security (e.g. 20 km/h in France [3]). Fast deadheadings represent the moves to go from the depot to the first collect link, from the collection area to the waste disposal site (and back), from one collection area to another, and from the waste disposal site to the depot.

Fig.1 : Description of a route



** FDh : Fast Deadheading.*
*** Within the collection area, a round is composed of collection phases and slow deadheadings*

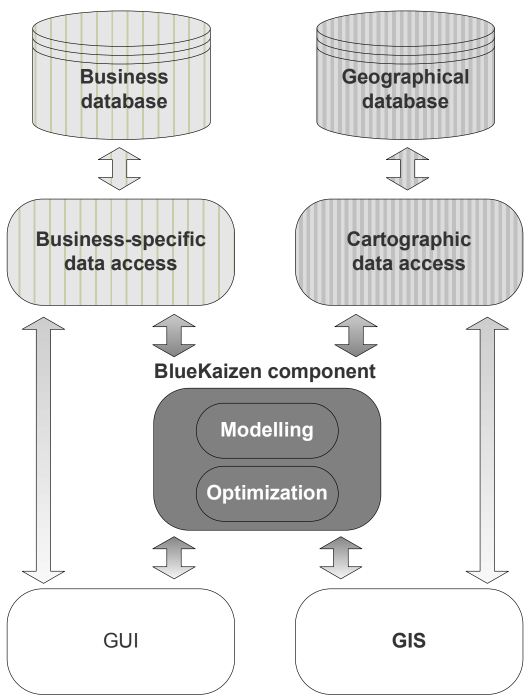
When design offices or local authorities define a new collection organization (for a new area, for a new waste type…), a planner must take all these aspects into account to define the routes. The process is still largely manual. Tools such as Geographical Information Systems (GIS) can help the planner visualize nice maps, draw routes or collection areas, but the operational details are still in their heads. Optimization is often done through rules of thumb.

General approach

Our goal is to provide planners with a tool that help them optimize their collection organization in a quantitative way: even in fully manual mode, a decision support system should check constraints, so that there is no “typing error”, and provide feedback (usually in the form of indicators), so that the consequences of decisions can be immediately assessed. Then, a more automatic mode should provide possible solutions that the planner can choose from and modify. The suggested solutions should be “optimized” according to certain criteria.

However, there is no point in finding the optimum using a simplified model, since the corresponding solution is often difficult to implement in real life. Our approach is first to build a precise and detailed model of the process, in conjunction with the end-users. This model is used as a simulation module, enabling any solution, whether generated manually or automatically, to be fully built (e.g. with precise road books) and evaluated (constraint violations, performance indicators). We then plug our optimization engine and adapt it. A fair amount of time is also dedicated to developing a user-friendly graphical interface, to enable rapid manipulations and analyses. The resulting decision support tool has the following architecture (Fig.2).

Fig.2 : Architecture of the decision support tool



The graphical user interface (GUI) includes a map representation (GIS); the tool needs two types of data: business-specific data (described below) and geographical data (geometric description of the road network, features such as number of lanes, one-way or two-way, speed limits…).

Our tool was developed with French customers, so all the parameters, business rules and constraints correspond to the French context. However, the architecture of the model is modular and flexible enough to be easily adapted to other contexts.

Municipal Waste collection process model

An accurate modelling of the collection process and its general organization is of major importance to perform an efficient and realistic optimization [1]. This section describes how the proposed tool integrates a comprehensive knowledge base of data and business rules specific to the waste management activity: the tool takes into account infrastructures data, human and material resources data, road networks, waste generation data, as well as collection areas.

Infrastructures data

Three types of locations are taken into consideration within the software: depots, waste disposal sites, and other locations (e.g. cleaning area, weight-in site, etc). Varied parameters can be defined. Some are common to all the sites and others are specific. The common parameters are: a name, a postal address, a geographical localization defined thanks to a geocoding tool and opening hours.

As regards to the depots, the user can also indicate an average waiting time as well as a list of equipments (e.g. gas station).

Concerning waste disposal sites, it is possible to indicate an average waiting time, a type of site (landfill, incinerator, sorting facility, etc.), the availability of a scaling system, the accepted types of waste and a site to visit before entering or afterwards.

Human and material resources data

The proposed model allows creating drivers models, as well as vehicles models. Drivers are defined with the following parameters: a name, weekly and daily working time windows, weekly and daily maximum working time. It is also possible to add time windows for breaks.

Vehicles are defined with varied parameters: a name, a height and a width, an unloading duration, a speed profile, a global payload (to define the point at which the vehicle must be unloaded at a disposal site), one or more compartments. Each compartment has a specific payload, depending on both the type of waste and its compressed density.

As soon as human and material resources have been created, it is possible to add teams' models that will be used by the optimization engine to determine the best collection service organization. A team corresponds to the association of one driver model with one vehicle model. It is also defined with a number of loaders and a loader coefficient. This coefficient stands for the fact that the speed collection varies with the number of loaders.

Road networks

For each deadheading phase, specific speed limitations are defined, which depend on the type of road (six types are distinguished). A distance threshold corresponding to the "fast deadheading" phase is specified by the user. As long as this threshold is not reached, parameters related to the "slow deadheading" phase are applied.

All geographical data are taken from existing data but an additional edition module enables the overload of specific data, such as traffic organization. Each link of the network can be edited in order to add access restrictions, specify lanes dimensions (maximal width and height), or to modify a one-way lane into a two-way lane. These parameters are then taken into account within the route determination. For instance, the optimization engine will check if the vehicle and its load fit safely on a road and the most appropriate vehicle will be chosen to respect these dimensional constraints.

Waste generation data

Different waste types can be modelled. A collection organization corresponds to one or several waste types to be collected simultaneously (multi-flux).
Reliable information on the weight and volume of waste to collect is not always easy to estimate, all the more so at the level of each container. The amount of municipal waste is highly variable and the accumulation of waste depends on several factors such as lifestyle, habitat type, population density, etc. [2]. A global weight and volume (over a year, for the whole collection area) is usually known. This has to be distributed at the level of a collection day, for each collect link.
The proposed tool provides two ways of defining the collected weight: by applying a distribution model to the global weight (distribution based on street lengths and/or population density) or by applying a waste generation model. While defining habitat types, the user can indicate a specific waste production rate (expressed in kg/inhabitant/week) for each type of waste and for a given population density (expressed as a range of inhabitants per kilometre). In order to determine the population density of a given area, the proposed tool needs to be fed with the population of this area. Such data can be either directly extracted from official data (databases on population) or manually indicated by the user.
When a collection area is created (see following paragraph), parameters on habitat types are used to obtain a realistic representation of waste generation and to estimate the total weight on the considered collection area.

Collection areas

The proposed tool allows the definition of varied collection areas and their characterization with specific parameters. Such a model is very flexible since the granularity of collection areas can be adjusted. Moreover, specific characterization can be set for each sector.
A collection area is defined for a given type of waste. It can either contain collect links, drop-off points, a mix of collect links and drop-off points, or a list of containers (imported from a file or manually created).
Depending on the type of collection area, a specific characterization consists in adjusting varied parameters. In the case of a collect link area, the following parameters can be defined: population density (and the associated waste generation), weight to collect, collection time-windows. Each collect link of a collect area can also be separately edited in order to indicate: specific time windows, the collect type (one or both sides), a possibly weight overload.
A drop-off point is defined by the following parameters: a time window, a duration and a collection time for each collection day.
A container is defined by the following parameters: a name, a type, a volume, waste type compatibilities and a localization.

A collection speed (expressed in tons per hour) is assigned to each collection area. This parameter is highly dependent on the linear weight production (expressed in tons per kilometre). Specific collection speeds can be assigned to varied ranges of weight production. This enables for instance to take into account the fact that the collection speed would be less important in a rural sector than in a very urbanized one (where linear weight production is higher). Collection speeds can also be manually adjusted by the user for each collection sector.

The collection speed and the linear weight production are both major parameters required to model the collection process. An important asset of the proposed tool is that varied means are available to quickly define these parameters without the need to set them individually for each collect link (individual links can still be characterized).

Municipal Waste collection optimization

Description of the optimization engine

Most realistic sized instances of practical combinatorial problems cannot be optimally solved, within a reasonable amount of time. Heuristics and metaheuristics are algorithms of choice. They attempt only to find good solutions rather than the best solution to the problem, but are able to tackle large and complex problems. Since there is no unique algorithm (and no unique combination of algorithms) that can be applied to all kinds of problems, we've been developing an optimization framework and a toolkit based on a set of heuristics and algorithms. This toolkit, called BlueKaizen™, enables us to rapidly develop hybrid optimization techniques, adapted to each problem, by combining different algorithms in different ways, and "playing" with them.

Route collection design and optimization criteria

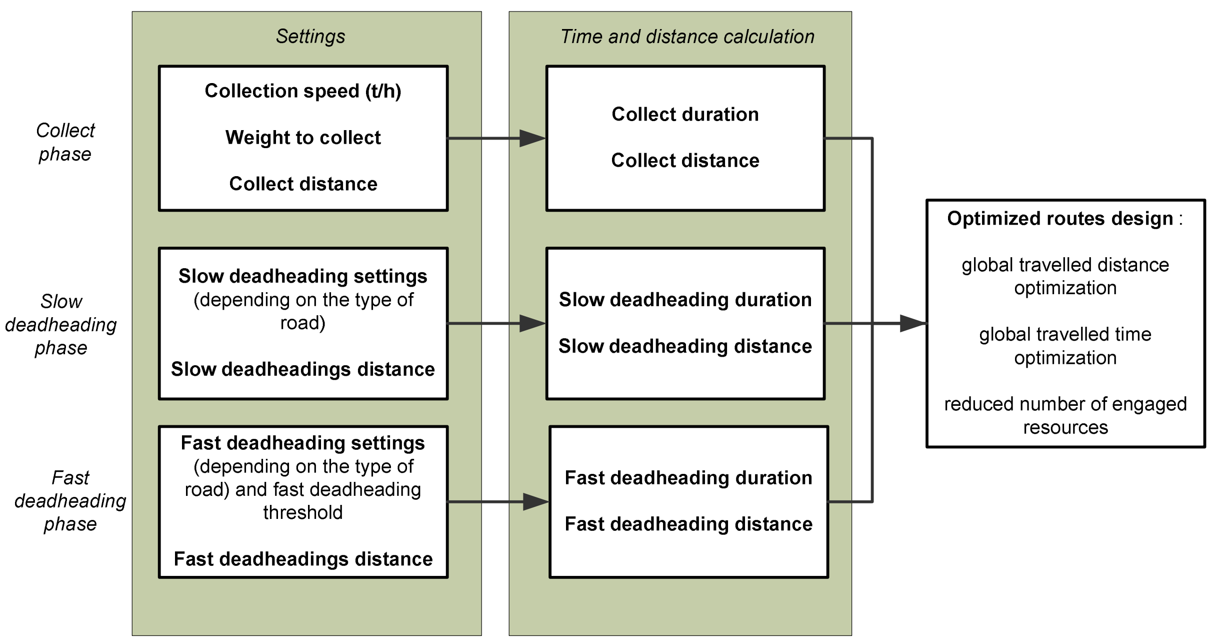
The routing algorithm implemented in our tool is largely inspired from the paper by Lacomme *et al.* (2002) [6]. It is basically an evolutionary algorithm in which chromosomes (solution representation) consist of sequences of links to collect. The simulation module transforms the sequences into feasible routes, inserting deadheadings (slow and fast) and tip trips wherever necessary. With respect to the paper, our algorithm takes into account additional constraints such as heterogeneous fleet of vehicles and access time windows.

As it builds the routes, the simulation module also assigns appropriate resources, picked heuristically from a heterogeneous fleet, taking into account capacity, collection speed and most importantly, access constraints (streets that are too narrow, turns that are too tight, bridges that are too low…). Capacity can correspond to multiple dimensions (e.g. a total volume and a total weight, or even several volumes and weights in the case of a combined multi-flux collection).

Built routes also integrate time constraints: begin times are determined with respect to the work shifts of the drivers and loaders; they are eventually shifted to take into account time slots on specific links; idle times are inserted for teams that take breaks (e.g. lunch).

Different optimization criteria can be used: minimization of the total working duration, minimization of deadheadings, or minimization of the total operational cost (which combines distance and time). Since the simulation module computes several indicators (Fig.3), it is easy to define different criteria and switch from one to another.

Fig.3: Global time and distance calculation to get optimized routes



Results and analysis

Case study

Varied tests have been pursued to assess the efficiency of the optimization model. One particular case study is explained in this paper. A data set related to a real trip (from a French urban area) has been incorporated within the software.

At first, the real route was reproduced without performing any optimization. All the collected links were retrieved (deadheadings were automatically recalculated by the software). This experiment allowed assessing the optimization degree of the real route. Then, the optimization engine was launched (the same collected links were retrieved but the sequence of these links was optimized). In each case, two ratios have been analyzed: collect length rate and collect duration rate.
Since results regarding the travelled length and spent time are not relevant outside the collection area, they have been analyzed within the collection area only. The optimization is more significant within the collection area where links sequence is reorganized.

Results are shown in Table 1. The real collection service was quite well organized but a thorough examination of the itinerary showed that many legal constraints were not taken into account. This could lead to a potential threat to worker's security. For instance, a lot of inappropriate U-turns were made and some both ways streets were unilaterally left-edge collected. Moreover, some other both-way streets were collected in a bilateral way, which is possibly dangerous.
The optimization performed with our tool takes into account all of the legal constraints in order to respect drivers' and loaders' security. Therefore, the new calculated travelled distance could be more important after optimization given that U-turns are not allowed in the software. Nevertheless, that distance might also be reduced given that the deadheadings are not the same (the sequence of collected links is recalculated, which induces a new calculation of deadheadings).

Table 1 : Case study results

	Real route (with infringements)	**Optimized route**	**Gain**
Collect length (length travelled during collect phase, which does not include deadheading length on collection area)	6.89 km	**6.89 km**	**--**
Deadheading length on collection area	15.49 km	**10.90 km**	**- 4.59 km**
Total length on collection area	22.38 km	**17.79 km**	**- 4.59 km**
Collect length rate*	30.78 %	**38.73 %**	**+ 7.95 %**
Collect duration (time travelled during collect phase, which does not include deadheading duration on collection area)	3 h 01 min	**3 h 01 min**	**--**
Deadheading duration on collection area	0 h 47 min	**0 h 36 min**	**- 11 min**
Total time spent on collection area	3 h 48 min	**3 h 37 min**	**- 11 min**
Collect duration rate**	79.38 %	**83.41 %**	**+ 4.03 %**

* Collect length rate = Total length travelled during collect phase / Total length travelled on the collection area
** Collect duration rate = Total duration of collect phase / Total time spent on the collection area

Results show a general increase in both collect length rate (+ 7.95 %) and duration rate (+ 4.03 %) after the optimization. Given that collect length and collect duration remain the same in both cases, the difference is due to a decrease in deadheading length and duration on collection area.
Therefore, the increase in deadheadings due to the forbidding of U-turns has been largely compensated by the reorganization of collect link sequences. An efficient optimization has consequently been performed.

This experiment shows that the proposed tool is able to optimize routes while legal constraints (including workers' security) are observed.

A tool in accordance with sustainable development

Greenhouse gas emissions due to waste collection service are not negligible: almost 600 millions tons of CO_2 are rejected within the atmosphere per year in France [5] and approximately 265 millions of kilometres are covered by collection vehicles each year [4]. Therefore, about 2kg of CO_2 are emitted per covered kilometre.

The proposed decision support tool could help reduce the impact of such an activity on climate change by reducing the number of resources engaged, as well as travelled distances.

If we assume that in average a reduction of 10% of the travelled distance can be achieved thanks to the proposed decision support tool, then a 60 000 tons decrease in carbon dioxide emission could be reached.

Moreover, if we consider that a collection vehicle consumes 60 litres of fuel per 100 kilometres and that each litre costs 1.30 €, then the global cost of fuel reaches more than 200 millions of euros. Again, if it is assumed that a reduction of 10% of the travelled distance can be achieved, then a 20 millions of euros decrease in fuel consumption could be performed.

As presented in the case study, the proposed decision support tool has been designed to optimize collection routes while workers' security is observed (specific speed limitations when the truck is in motion with loaders on the rear, possibility to forbid bilateral collect if it is estimated potentially dangerous, forbidding to go backwards). Therefore, this tool is also in accordance with sustainable development from a social point of view.

Conclusion and perspectives

With respect to standard versions of the capacitated arc routing problems, we managed to take into account operational constraints such as time slots, multi-compartments vehicles for combined collection and labour constraints (working hours, breaks).

The tool presented in this paper has been developed in France but aims at an international development. Each country has its own legal rules and local authorities might also require very specific parameters or rules to be taken into account. Since the operational model is independent of the optimization engine, the tool is flexible enough to be easily adapted to new contexts.

We realized that the optimization results in terms of travelled distance or working time reduction vary greatly with the case studied: some organizations are already well optimized, even manually, through constant improvements from both the drivers and the planners; some areas are difficult to optimize, with a lot of one-way streets; some are easy to optimize. We're currently trying to extract a more general result for the performance of our tool.

Even with a powerful optimization engine, a decision support tool is useless if it is not user-friendly. We are constantly improving the graphical user interface and working on ways to help the user enter all the data that are necessary before any optimization (such as collection weight distribution or collection weight generation). In this aspect, the introduction of statistical models might be interesting in the future.

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Underground waste transportation and conventional urban waste collection – how do they compare with regard to today's demands on the urban environment?

Jonas Törnblom

Biography

Jonas Törnblom, born 1958, is a graduate from the Stockholm School of Economics and since 2002 Director of Corporate Marketing and Communication at Envac Centralsug AB in Stockholm. Envac is the inventor and the leading supplier of underground waste transportation systems in the world. Mr. Törnblom is an active member in several committees and boards promoting technology for sustainable urban development in Sweden, such as "The Sustainable City – a Swedish Partnership Initiative", "The Swedish Environmental Technology Network" , "The Technology Development Committee for Hammarby Sjöstad" and SMTC, the "Stockholm Environmental Technology Centre". He has participated as an expert in waste management evaluation programs in Toronto, Cork and London and written several articles on the subject of urban waste management.

Summary

As an alternative to the conventional way of handling waste in denser urban areas (bins in waste rooms collected manually and transported away by means of rear loading trucks) the underground waste transport system, invented in Sweden in the early 1960:ies, is often applied in modern developments. The two systems approach waste handling from separate stand points, the former as being a house specific service and the latter as being part of a fixed infrastructure network.

The paper presents the environmental consequences of both systems in a planned urban development in Sweden. The environmental consequences have been assessed by means of simulation of the user's waste deposit behaviour. The environmental consequences that will be discussed are:

- Energy requirements for both collection systems
- Emmissions of carbon dioxide caused by the collection process
- Traffic implications as a result of types of users, types of waste, storage requirements and collection frequency
- Overfill and littering of waste receptacles due to seasonal variations in waste disposal patterns.

The paper also compares these findings with an actual urban development in London – the New Wembley area.

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Introduction

Waste collection is traditionally a municipal task and responsibility, and the choice of technology/method to cities waste problems is most often made within a single administration, even though these choices affect the city in many aspects beyond the specific waste handling. Hence, waste collection technology is not been exposed to the same holistic demands as other urban infrastructure services. However, political trends leading to increasing city density, constructing areas where work, leisure and living is combined, but at the same time being as environmentally advanced as possible affect also the way we store, collect and transport our urban waste.

The underground waste transport systems which were first introduced in Sweden in the late 1960s represented a new dimension in waste collection. Waste was no longer picked up manually or semi manually by a recurrent collection service, but became part of an underground grid, much the same as urban water and electricity supply or the evacuation of waste water/sewage.

How are the two methods of urban waste collection, storage in bins and containers inside or outside houses and underground storage and transportation? How are they compared cost wise and what is the opinion of the users and the municipality responsible for the collection of household waste? This will be studies at the background of two modern urban developments in Stockholm.

The areas and technologies compared

The two areas studied are both good examples of successful and popular new urban developments in the City of Stockholm. The areas have been built by both private and public developers and the flats are both owned by the inhabitants and rented. The inhabitants in both areas are characterised as middle income families with a tendency that Hammarby Sjöstad has a slighter younger population (more families with children) than the St. Eriks area.

Hammarby Sjöstad, has recently become an internationally renowned development. It is the largest construction project in Northern Europe at the time and was initially conceived to host the Olympic village for the 2004 summer Olympics, would Stockholm have won the candidature contest. When completed in 2015 10,000 dwelling will have been built in an area of 150 ha on the South East side of Stockholm, 8 km from the city centre. Hammarby Sjöstad is known as one of the best examples of sustainable urban design in the world today.. One of the focus areas have been to reduce heavy waste transports with 60%. One other waste handling has been to introduce a more elaborate source separation scheme than in any other part of town.

In 2005 the St. Eriks area in the Stockholm borough Kungsholmen was awarded the Philippe Rothier EUROPEAN PRIZE FOR ARCHITECTURE for town and city reconstruction. Five other European urban projects among 68 contenders from 18 countries were awarded the same price. The motivation from the international jury was: ”The new urban district Sankt Eriks hospital area in Stockholm, Sweden, is designed by the City architect Alexander Wolodarski. The district offers a sustainable environment of high quality, both in terms of the disposition of the area as well as in terms of the design of the streets, places and parks as well as the beauty of the classical architecture.”

The Sankt Eriks district, which was built 1996-1998 encompasses an area with 750 dwellings in multi-family houses.

The St. Eriks area has no particular ambition to be better than the average in terms of environmental issues. It follows the requirements and standards in Sweden when it comes to waste handling and uses conventional waste storage rooms in each building handling botrh household waste, packaging and bulky waste.

In Hammary Sjöstad two waste collection systems are currently used. The first being a Mobile Vacuum System, being installed in 199X for xxxx number of dwellings. This system currently handles two waste fractions; household waste (non-recyclables) and organic waste. At the end of 2005 a Stationary Vacuum System was installed for the collection of three separate fractions; household waste (non-recyclables), paper and organic waste. For the collection of other waste types, such as glass, packaging materials and bulky waste bins are used, located in a special waste room in the housing block.

Comparison of the waste handling systems in the St Eriks area and in Hammarby Sjöstad.
First of all it is important to note that the municipalities in Sweden are only responsible for the collection of the so-called household waste. The collection of all packaging waste (glass, cardboard, paper, plastics etc.) is not a municipal responsibility, but a responsibility of the packaging industry. The packaging industry is completely responsible for the collection of all packaging waste and subcontracts this service in turn to private entrepreneurs.

The economic comparison below excludes the collection of packaging waste because packaging waste is never handled by underground waste transport systems in Sweden (unlike in many other European countries). The reason for this is purely due to the fact that the packaging industry has yet not been willing to invest in the technology. In some occasions, however, like in Hammarby Sjöstad the paper fraction is handled as a separate fraction by the underground waste transport system.

Newly constructed multi-family dwellings in Stockholm have access to a waste room located at the entrance level of the building, accessible from either the inside or the outside of the building. In this waste room not only the household waste is stored, but also the packaging waste, paper (newspapers, magazines etc.), bulky waste and electronic waste. There are no special national building requirements for the location and design of waste storage facilities in multi-family dwellings, but RVF, the Swedish Association of Waste Management has issued a set of recommendations[1]. These recommendations aim at not only securing a safe, easy and comfortable disposal for the users, but it also safeguards that occupational health and safety requirements for the waste collectors as well as special requirements for disabled persons are fulfilled.

When an underground waste transport system is installed the inlets are often installed in the court yard of the housing bloc (see picture below). This solution has proven to be both cost efficient (several buildings share one inlet point) and appreciated by the users (there is a certain amount of social control as the inlets are well exposed to the flats surrounding the courtyard). As an alternative to court yard inlets the architects sometimes put the waste inlets next to the entrance (this has the advantage that the inhabitants don't need to be exposed to snow and rain when disposing of their waste), or inside the waste rooms where also the packaging waste is handled. The first type of installation, in the courtyard, is, however, getting more and more popular over the other two despite the weather factor.

[1] RVF Utveckling 02:12 ISSN 1103-4092


Picture 1: waste inlets installed in a court yard of a housing bloc in Hammarby Sjöstad.


Picture 2: waste inlet located in the entrance hall of a building.

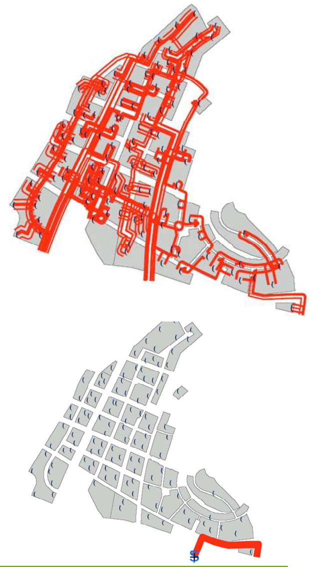
Comparison
The two systems compared for the handling of the household waste are the underground waste transport system and the traditional collection of bins by means of a rear loading truck. The comparison covers the following aspects of waste handling:

Costs installation, handling and collection - **Hammarby Sjöstad**
Social Peoples attitude towards their waste collection and handling in **Hammarby Sjöstad and the St Eriks area**

In an environmental comparison for the neighbourhood it is obvious that the underground waste transport system has advantages over traditional, manual waste collection. The compasrison below from another urban are in Stockholm demonstrates the differences:

Environmental impact from waste collection traffic

per year	Conventional	UWT System
Driving distance	2 881 km	250 km
No. of street crossings passed	19 188	1 972
No. of hours the waste truck spends in area	4 238 h	213 h



Picture 3. Comparison of an assessment of the collection route intensity of conventional waste handling and underground waste transportation in a residential area to built in Stockholm

Cost comparison

The below economical comparison between a conventional collection system and a stationary vacuum system was commissioned by the City of Stockholm and carried out by the Swedish consultant company SWECO in 2005[2]. The comparison of the two alternative systems is based on the **2 095 apartments** that will be built in the phase called Västra Sjöstaden (planned completion 2007). The study compares the handling three waste categories (non-recyclables, organic and a paper fraction.

The investment comparison considered the necessary dimensioning criteria for container handling with the conventional collection system (two-wheeled bins of 140, 240 and 370 litres capacity depending on fraction density) based on the restrictions on pulling and carrying waste bins/containers in place in Sweden[3].

Investment. The investment costs include costs for technical equipment, construction costs for valve rooms, terminal station, system installation, commissioning, maintenance and repair and civil works for the complete underground waste transport system. The investment costs for the conventional system include technical equipment (bins; 140, 240 or 370 liter depending on fraction, 10 years life) and construction of waste rooms (totally 1,367 m^2, or 26m^2 per building). The economical comparison is made over 20 years.

Alternative revenue for released space on ground level for the underground system is assessed on the basis of average annual rents for commercial premises in the area at SEK 1500/sqm and year.

Yearly operational costs include operational, maintenance and collection costs (based on the official tariffs from the City of Stockholm) as well as the energy costs for the vacuum systems. The collection fees set by the City of Stockholm vary with the type of collection system applied. The collection fee

[2] Hammarby Sjöstad – Västra Sjöstaden, Comparison of manual waste handling and a stationary system for 3 fractions, 05/04/2005, Sweco Viak AB

[3] [3] Eliminate overweight – information sheet from the Swedish Transport Workers Association, Box 174 Olof Palmes Gata 29, SE-101 33 Stockholm.

today is 2.47 times higher for households with manual collection than with underground collection systems.

CALCULATION **With 4%, rental income ground floor premises**	**Investment collection system** SEK	**Operating costs, collection system,** SEK/year	**TOTAL Operating and capital cost** **4% cost of capital** **SEK/year**
Manual handling, containers One reinvestment of containers year 10	27 133 043 SEK	2 814 839 SEK/year	**5 083 189 SEK/year**
Underground waste transport system, primary + secondary network	44 275 000 SEK	823 099 SEK/year Rental income: -2 049 942 SEK/year Net: - 1 226 842 SEK/year	**2 030 990 SEK/year**

Table 1. Investment and operational cost comparison of two waste collection systems for phase 2 of Hammarby Sjöstad.

As demonstrated in the table above is the underground waste transport system in a 20 years perspective considerably more profitable, with a payback time of around 15 years.

Social comparison – user satisfaction

In order to be able to acquire a response from the users about their waste handling facilities that would be comparable also with other population groups and other collection technologies a standardised questionnaire from RVF has been used[4].

57 households in Hammarby Sjöstad and 52 in the St. Eriks area have answered the 23 questions in the questionnaire (enclosure).

The results of the attitude study.

In general the responding households had a generally positive attitude towards their waste handling. The results from the study did not differ that much between the two areas. A larger difference was expected prior to starting the study. One reason for the comparability of the results were that the study did not compare conventional bins/containers with the underground waste transport technology. The inhabitants in Hammarby Sjöstad have both the underground waste transport system as well as bins for the collection of their packaging waste. The waste inlets for the underground system in Hammarby Sjöstad are located either inside the buildings in the waste room, adjacent to the entrance in the outer wall of the building or as free-standing inlets in the court yards. The second and the third alternative were the most favoured solutions by the inhabitants when asked more specifically. The questionnaire did not, however, allow for a specification of the attitude towards a certain type and location of inlets. Therefore only a comparison of the general level of satisfaction with the waste handling in general between the two areas can be made. A more specific analysis of the attitude towards one particular system will be subject to the next study.

[4] RVF Branschindex – RVF Utveckling rapport 2004:14 (Swedish only)

Question

1 = not at all 3 = neither nor 5 = agree fully 6 = I don't know

			1	2	3	4	5	6
1	The waste handling in my area is environmentally friendly	St Erik	0,00%	11,54%	42,31%	23,08%	11,54%	11,54%
	The waste handling in my area is environmentally friendly	Hammarby Sjöstad	1,75%	3,51%	8,77%	35,09%	40,35%	10,53%
2	The waste handling in my area is cost effective	St Erik	0,00%	5,88%	23,53%	11,76%	7,84%	50,98%
	The waste handling in my area is cost effective	Hammarby Sjöstad	3,51%	1,75%	19,30%	21,05%	8,77%	45,61%
3	The waste handling in my area is modern and rational	St Erik	3,85%	7,69%	26,92%	32,69%	13,46%	15,38%
	The waste handling in my area is modern and rational	Hammarby Sjöstad	0,00%	3,51%	19,30%	38,60%	26,32%	12,28%
4	I'm very confident that my seggregated waste is recycled correctly	St Erik	0,00%	25,00%	25,00%	27,08%	8,33%	14,58%
	I'm very confident that my seggregated waste is recycled correctly	Hammarby Sjöstad	3,51%	1,75%	29,82%	26,32%	33,33%	5,26%
5	All in all I have confidence in the way the waste handling in my area is handled	St Erik	0,00%	15,38%	13,46%	57,69%	5,77%	7,69%
	All in all I have confidence in the way the waste handling in my area is handled	Hammarby Sjöstad	1,75%	0,00%	22,81%	42,11%	28,07%	5,26%
6	It is important to segregate one's waste	St Erik	0,00%	7,69%	9,62%	38,46%	44,23%	0,00%
	It is important to segregate one's waste	Hammarby Sjöstad	3,51%	3,51%	8,77%	40,35%	43,86%	0,00%
7	It is easy to segregate one's waste	St Erik	3,85%	13,46%	21,15%	28,85%	30,77%	1,92%
	It is easy to segregate one's waste	Hammarby Sjöstad	5,26%	14,04%	12,28%	31,58%	35,09%	1,75%
8	I generally seggregate my waste	St Erik	5,77%	3,85%	13,46%	44,23%	32,69%	0,00%
	I generally seggregate my waste	Hammarby Sjöstad	3,51%	5,26%	10,53%	40,35%	40,35%	0,00%

9	The waste disposal facilities are clean, nice and well maintained	St Erik	5,77%	13,46%	23,08%	46,15%	11,54%	0,00%
	The waste disposal facilities are clean, nice and well maintained	Hammarby Sjöstad	8,77%	8,77%	21,05%	38,60%	19,30%	3,51%
10	… are located at a conveniant location	St Erik	3,92%	1,96%	15,69%	39,22%	37,25%	1,96%
	… are located at a conveniant location	Hammarby Sjöstad	3,51%	3,51%	15,79%	33,33%	42,11%	1,75%
11	… are generally never overfilled nor defect	St Erik	5,77%	19,23%	19,23%	34,62%	17,31%	3,85%
	… are generally never overfilled nor defect	Hammarby Sjöstad	22,81%	24,56%	21,05%	22,81%	7,02%	1,75%
12	… are adapted to accomodate my waste with regard to size and volume	St Erik	3,85%	11,54%	5,77%	50,00%	25,00%	3,85%
	… are adapted to accomodate my waste with regard to size and volume	Hammarby Sjöstad	5,26%	17,54%	28,07%	29,82%	17,54%	1,75%
13	There are good possibilities to dispose of seggregated organic waste	St Erik	48,08%	13,46%	5,77%	15,38%	13,46%	3,85%
	There are good possibilities to dispose of seggregated organic waste	Hammarby Sjöstad	0,00%	1,75%	7,02%	31,58%	56,14%	3,51%
14	There are good possibilities to dispose of seggregated packaging waste	St Erik	7,69%	3,85%	13,46%	23,08%	50,00%	1,92%
	There are good possibilities to dispose of seggregated packaging waste	Hammarby Sjöstad	1,75%	0,00%	5,26%	38,60%	50,88%	3,51%
15	There are good possibilities to dispose of seggregated paper waste	St Erik	0,00%	1,92%	1,92%	15,38%	78,85%	1,92%
	There are good possibilities to dispose of seggregated paper waste	Hammarby Sjöstad	3,51%	3,51%	8,77%	28,07%	54,39%	1,75%
16	There are good possibilities to dispose of seggregated non-recyclables	St Erik	1,92%	1,92%	11,54%	23,08%	53,85%	7,69%
	There are good possibilities to dispose of seggregated non-recyclables	Hammarby Sjöstad	1,75%	3,51%	17,54%	26,32%	49,12%	1,75%
17	My waste handling does not cause disturbing noise and sound	St Erik	3,85%	17,31%	15,38%	28,85%	30,77%	3,85%
	My waste handling does not cause disturbing noise and sound	Hammarby Sjöstad	10,53%	5,26%	19,30%	17,54%	43,86%	3,51%

18	My waste handling is free from bad and uncomfortable smells/odours	St Erik	5,77%	26,92%	25,00%	30,77%	9,62%	1,92%
	My waste handling is free from bad and uncomfortable smells/odours	Hammarby Sjöstad	3,51%	14,04%	17,54%	33,33%	28,07%	3,51%
19	I have never seen rats or vermine in conjunction with the waste handling	St Erik	3,85%	0,00%	7,69%	17,31%	69,23%	1,92%
	I have never seen rats or vermine in conjunction with the waste handling	Hammarby Sjöstad	1,75%	0,00%	8,77%	14,04%	73,68%	1,75%
20	My waste handling is secure and free of hazards	St Erik	3,85%	1,92%	17,31%	26,92%	36,54%	13,46%
	My waste handling is secure and free of hazards	Hammarby Sjöstad	1,75%	1,75%	19,30%	38,60%	29,82%	8,77%
21	I have good knowledge of how I shall handle my waste	St Erik	0,00%	5,77%	30,77%	34,62%	25,00%	3,85%
	I have good knowledge of how I shall handle my waste	Hammarby Sjöstad	3,51%	0,00%	19,30%	42,11%	35,09%	0,00%
22	I am satisfied with the information I get about the waste handling	St Erik	3,85%	13,46%	19,23%	40,38%	21,15%	1,92%
	I am satisfied with the information I get about the waste handling	Hammarby Sjöstad	5,26%	5,26%	24,56%	31,58%	33,33%	0,00%
23	I am all in all satisfied with the waste handling in my area	St Erik	1,92%	7,69%	23,08%	57,69%	9,62%	0,00%
	I am all in all satisfied with the waste handling in my area	Hammarby Sjöstad	1,75%	0,00%	21,05%	59,65%	15,79%	1,75%

Table 2. Survey of user attitudes towards their waste handling systems in the St. Erik area and Hammarby Sjöstad, both in Stockholm.

The inhabitants in both areas are generally satisfied with their waste handling systems as can be seen by the above table. There is a general belief that the system in Hammarby Sjöstad is more environmentally friendly than in St Erik (Q 1). None of the inhabitants can judge if their waste collection system is particular cost effective (Q 2). The inhabitants in Hammarby Sjöstad are more confident about the recycling and source separation aspects than the inhabitants in St Erik (Q 4). The clear difference in how the inhabitants perceive the possibilities to segregate the organic waste (Q 13) should be seen against the fact that there is no separate collection of organic waste in St. Erik. The opinion about the segregation possibilities of packaging and paper waste are comparable (Q 14 and 15) in both areas because the handling is similar (bins in waste rooms), apart for a few of the households that have paper/magazine inlets connected to the underground transport system.

The difference in the perception of smells and odours (Q 18) is to be attributed to the difference in the location of waste disposal facilities (inlets). Hammarby Sjöstad has mostly out door for two or three fractions, as mentioned above. The inhabitants in Hammarby Sjöstad also express a better knowledge of how they should handle their waste (Q 22) and are more satisfied with their waste handling (Q 23).

Conclusions

In order to arrive at a comprehensive comparison between the two waste handling systems in question several aspects must be evaluated. The economical comparison should not only compare the investment against the collection costs. It should also consider and evaluate the occupied space inside/outside buildings, operational and maintenance costs. It should also take the difference in collection costs resulting out of the lower tariffs from the City of Stockholm for vacuum systems into account.

The above comparison of two different waste handling systems for multi-family dwellings demonstrate some favourable aspects for the underground waste transport system. The total costs, in this example, over a 20 year time span is considerably lower for the underground waste transport system. This is often not apparent since there is a general belief that there is no investment costs associated with providing facilities for conventional waste collection.

The other important aspect is user satisfaction. The study shows that the users in Hammarby Sjöstad have a better opinion about the environmentally friendliness of the waste handling system and its possibilities for waste segregation. The users also see the underground waste transport system as more modern and rational and have in general a more favourable attitude towards their waste handling.

Underground waste transport systems can be, in contrary to many assumptions, be both less expensive than a conventional manual waste handling system considering the all costs directly and indirectly associated with the municipal waste collection. An underground waste transport system can also result in a higher user satisfaction and a more positive attitude towards waste segregation.

Waste collection optimisation tools for waste managers

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Tom Clifford is a Chartered Environmentalist, Chartered Waste Manager and Member of the Chartered Institution of Wastes Management. He is a former local authority waste manager and in that role held positions with the National Association of Waste Disposal Officers, CSS Waste Management Committee and National Household Hazardous Waste Forum. He moved to consultancy following a successful PFI procurement on behalf of South Gloucestershire Council. He has previous worked for Atkins and is currently Managing Consultant with Indecon Limited.

Purpose

To introduce the audience to two software tools – CostCalculator and RouteCalculator - developed by Indecon Limited that can assist local authority waste managers in optimising waste collection activities.

Scope

The presentation will deal with, as the first stage optimisation process, using CostCalculator, the comparative assessment of the resources required for different waste collection scenarios based on tonnage arising, vehicle capacity and productivity for the entire collection area. The second stage of the optimisation process and the role of RouteCalculator in planning and optimising collection rounds will then be introduced.

Method

Both tools are intended to be used by waste managers with typical PC skills and are built on propriety software products. CostCalculator is a MS Excel based workbook whilst RouteCaculator uses MS MapPoint interfaced with bespoke graphical user interface. The presentation will introduce the audience to these models.

For CostCalculator each worksheet within the model will be explained. Using a test example the presentation will show how the model seeks to achieve the best balance between payload and productivity, which may offer energy savings with regard to fuel usage.

RouteCalculator allows users to build and balance rounds based on the arisings, vehicle capacity and productivity data generated by CostCalculator. In the initial design of routes, this is done using 'free-hand' polygons. The routes are then refined through an iteration and optimisation process which, through the software, identifies the most efficient collection route for the properties within a given boundary, based upon a number of collection parameters such as location of the delivery point, average speed etc.

The optimisation process is designed to minimise non-productive journey time, mileage, fuel usage etc and thus reduce the environment impact of waste collection. This is represented within RouteCalculator by a CarbonCalculator sub-routine which presents the environmental impact of the collection system as the number of trees required to off-set the fleet's carbon emissions.

Results

Both real and test results will be presented in the form of outputs from the models. These comparative results will demonstrate how differences in resources and collection routes are driven by a variety of operational parameters.

Conclusions

The presentation will demonstrate how the use of these types of tools can help optimise waste collection activities and thus energy savings associated with fuel usage.