Improving the municipal solid waste collection through an optimized route planning

A study conducted within the municipality of Växjö
Acknowledgments

The authors of the present thesis have had the privilege to accomplish a three months case study regarding the improvement of Växjö municipality’s municipal solid waste collection through an optimized route planning. In particular, the accomplishment of this thesis would not have been possible without the support and tight collaboration of Växjö Municipality’s personnel. Indeed, we would like to address our deepest thanks to Per Gunnarsson, head of Växjö’s waste department, who gave us the opportunity to write this thesis. Additionally, we thank Gert Hansson, the general manager of Ragn-Sells Växjö and Paul Herbertsson, the head of planning department for their willingness and dedication to help us during the data collection process in order to complete this case study. Similarly, we would like to thank Petteri Maukola, the key account manager at Enevo who had devoted his time to share pertinent information for this master thesis.

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Växjö, May 29th 2014

Sabine Garimé         Martin Duru         Esteban Ramirez         Moritz Knecht

____________________  __________________  __________________  __________________
Summary

Linnaeus University Växjö, School of Business and Economics, Business Process and Supply Chain Management, Degree Project (master), 15 higher education credits, Course 4FE06E, Spring 2014

Authors: Sabine Garimé, Martin Duru, Esteban Ramirez, Moritz Knecht

Tutor: Roger Stokkedal

Examiner: Helena Forslund

Title: “Improving the municipal solid waste collection through an optimized route planning - A study conducted within the municipality of Växjö”

Background: Municipal solid waste includes household waste and similar waste created by commerce and institutions, which is in this case study collected by the contractor Ragn-Sells on behalf of the municipality of Växjö. Municipal solid waste collection is the process of collecting such waste. Route planning is used to optimize the routes for the collection of bins. With the help of route planning systems, the municipal solid waste collection is planned and managed.

Problem discussion: Several issues with municipal solid waste collection in Växjö municipality were identified due to the lack of information regarding the quantity of waste in the bin collected. This issue leads to difficulties in the route planning causing high unnecessary costs and environmental impacts. There are several political and socio-demographic constraints, which would need to be overcome when changing the municipal solid waste collection.

Research questions:

RQ1: How can the municipal solid waste collection in Växjö municipality be improved through an optimized route planning?

RQ2: How can Växjö municipality and Ragn-Sells AB reduce the environmental impacts of the municipal solid waste collection by optimizing the route planning?

RQ3: How can Växjö municipality reduce their municipal solid waste collection costs by optimizing the route planning?

RQ4: What are the constraints when changing the municipal solid waste collection in Växjö municipality and how can they be overcome?
Method: This thesis represents a case study conducted via a hermeneutic perspective and a deductive approach. Data were collected by personal interviews, a telephone interview, observations and mailing of questionnaires, as well as academic literature procured via research in Linnaeus University’s library. The results of the case study have been based upon qualitative information but only few quantitative data collected from the studied companies.

Conclusion: The results of the study show that if Växjö municipality can monitor the quantity of waste in the bins by the means of modern traceability devices (e.g: sensors), their current route planning system would be more efficient. Therefore, a new route planning system with sensors for Växjö municipality is suggested in order to improve their municipal solid waste collection. As a result of the improvements, the municipality of Växjö can expect lower costs and environmental impacts. Several constraints are refraining the potential changes in Växjö municipality’s municipal solid waste collection. Nevertheless the constraints could be overcome, for instance by arguing for the lower costs and environmental impacts.
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List of Abbreviations

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<td>Capacitated Vehicle Routing Problem</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<td>GPRS</td>
<td>General Packet Radio System</td>
</tr>
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<td>GPS</td>
<td>Global Position System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile communication</td>
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<tr>
<td>KNEG</td>
<td>KlimatNeutrala Godstransport på väg</td>
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<td>MSW</td>
<td>Municipal Solid Waste</td>
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<td>MSWC</td>
<td>Municipal Solid Waste Collection</td>
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<td>MSWM</td>
<td>Municipal solid Waste Management</td>
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<td>RCV</td>
<td>Refuse Collection Vehicles</td>
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<td>RFID</td>
<td>Radio Frequency Identification</td>
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<td>RME</td>
<td>Rapeseed-oil Methyl Ester</td>
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<td>RPS</td>
<td>Route Planning System</td>
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<td>SVRP</td>
<td>Stochastic Vehicle Routing Problem</td>
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<td>VRP</td>
<td>Vehicle Routing Problem</td>
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<td>VRPTW</td>
<td>Vehicle Routing Problem Time Windows</td>
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1 Introduction

The introduction chapter presents the general background and problem discussion of the municipal solid waste collection in Växjö. The purpose and research questions are based upon the issues found in the problem discussion and will form the structure of the thesis. Subsequently, limitations are described and the outline of this thesis graphically illustrated.

1.1 Background

1.1.1 Municipal Solid Waste

A municipality is an organized administrative district that encompasses several places such as a city, town or village and has a corporate status (Sullivan, 2009). The Organisation for Economic Co-operation and Development, a group of 34 member countries that develop economic and social policies, defines Municipal Solid Waste (MSW) as the total waste collected by or on behalf of municipalities, which includes household waste and similar waste created by commerce and institutions (OECD.org, 2008).

Municipal Solid Waste Management (MSWM) represents a number of processes that are involved in managing solid waste for a municipality, which includes monitoring, collecting, processing, recycling and disposing (Faccio, et al., 2011). The challenges for MSWM are constantly increasing as a result of urbanisation and higher lifestyle quality in the world (Cheng and Hu, 2010). According to Rajendran, et al. (2013), the local governments are responsible for collecting and processing waste. Sweden has been one of the leading countries in the world regarding MSWM. Garbage fees, easy accessible recycling stations and awareness campaigns has led to an increased recycling rate in Sweden (Ibid). The policy for MSWM in Sweden is based on a framework from the European Union, which is used by the Swedish parliament to develop the MSWM rules (Avfall Sverige, 2013).

MSW excludes waste that fall under the producers responsibility, which is an important regulation of the Swedish waste management. The producers are in charge of collecting and handling waste in the field of the products they produce. It includes products such
as batteries, cars, tiers, electronic material, packaging, paper, medicine, and radioactive products (Naturvardsverket.se, 2014).

1.1.2 Municipal Solid Waste Collection

Municipal Solid Waste Collection (MSWC) is the process of collecting and transferring MSW to the place of treatment (OECD.org, 2001). MSW is collected by municipalities (Cheng and Hu, 2010) and is carried out by Refuse Collection Vehicles (RCV) (Apaydin and Gonullu, 2008; Faccio, et al., 2011). Although the interest of recycling and reducing waste is growing in the world, the collection of waste has not been as efficient as expected (Virtanen and Nilsson, 2013).

Managers frequently struggle to decide the most accurate performance improvement strategy to achieve efficiency (Fugate, et al., 2010). Efficiency refers to doing things in the correct way and is focused on achieving the maximum output with the minimum input (Productivity Commission, 2013). One of the key elements of MSWC, showed by Chang, et al. (2012) and Koroneos and Nanaki (2012), is the overall goal to improve the collection performance through a more efficient manner. According to some scholars, route planning refers to the optimization of a number of routes of minimum length for the RCV’s (Wang, et al., 2008; Kuo and Wang, 2011). Route planning systems (RPS) are technological solutions and are used to accurately plan and manage the MSWC (Nuortio, et al., 2006; Islam, et al., 2014).

Nuortio et al. (2006) claimed that an efficient MSWC has both positive environmental impacts and economical effects. Besides costs concerns there are several reasons for optimizing route planning including health and environmental aspects (Ibid). A major issue with the collection of MSW in comparison to other freight transportations is the slow speed of the RCV’s and numerous stops which leads to higher congestion, emission, noise and air pollution. Although, there are several issues regarding route optimization, cost is the main argument and measurement for decision making in MSWC (Bing, et al., 2014).
1.1.3 Municipal Solid Waste Collection In Växjö

The municipality of Växjö is situated in south-east Sweden and has 84,000 inhabitants, while 60,000 of the population live in the city of Växjö (Smas, et al., 2013). The municipality of Växjö divides the collection of MSW into two main geographically separated areas, which are the rural area and the urban area. The urban areas represent the city of Växjö and some nearby suburbs, while the rural areas encompasses smaller villages located on the countryside of the municipality (Head of Växjö’s waste department, 2014-04-11).

The municipality defines customers as the inhabitants that generate waste, which is collected from the municipality. The customers include households (villas and apartment blocks), commercial establishments and institutions (Head of Växjö’s waste department, 2014-04-11). Växjö municipality is responsible for the MSWC of the entire municipality, which is divided into urban and rural areas. Ragn-Sells AB (hereafter Ragn-Sells), is a private contractor which collects since 2011 MSW on behalf of the municipality Växjö from the customers. The municipality provides their customers with two types of waste bins in which customers can throw their MSW. The customers sort two types of MSW, which encompass food waste and mixed waste (e.g. packages). Those two kind of bins are collected by Ragn-Sells. In addition, the customers can leave their bulky, garden, hazardous and electronic waste in eight recycling centrals positioned around the municipality (Head of Växjö’s waste department, 2014-04-11).

The MSWC is monitored and managed through a route planning system which integrates a number of sophisticated technologies. The route planning is based on the interactivity of these technologies and manual operations, which allows the municipality to collect the MSW in a more efficient manner (General manager of Ragn-Sells Växjö, 2014-04-10).

1.2 Problem Discussion

Although, solid waste quantities have declined in Sweden during 2011 (Avfall Sverige, 2011), they rose slightly in 2013 compared to previous years (Avfall Sverige, 2013). Swedish municipalities have a key role to define the motor of change and act as the guarantor of long-term and sustainable MSWM (Ibid). The following four issues are the
main challenges towards MSWC in Växjö’s municipality as stated by the general manager of Ragn-Sells Växjö (2014-04-10), and by the head of Växjö’s waste department (2014-04-11).

1.2.1 Route Planning
The general manager of Ragn-Sells Växjö (2014-04-10) claimed that several challenges have risen in the MSWC in Växjö municipality in terms of long distance between the customers, the time spending on the roads and the multiple stops when collecting the bins. Moreover, Ragn-Sells is currently estimating the amount of waste in the bins based on historical data. The waste inside the bins is on average filled up to three quarters although there is a high variety of the amount between the different customer bins. Therefore, it is rather difficult to predict how many bins each RCV can collect before the RCV reaches its capacity limit (General Manager Ragn-Sells Växjö, 2014-04-10).

In addition, the drivers of the RCV’s are assigned with certain areas to collect MSW. However, the order of the collection is not predefined, which lead to difficulties to optimize the route planning of the MSWC in advance (General manager of Ragn-Sells in Växjö, 2014-04-10).

1.2.2 Environmental Impacts From Municipal Solid Waste Collection
Ragn-Sells is a member of the Klimatneutrala Godstransport På Väg network (KNEG), which has set the goal of reducing emissions from Swedish transport companies by 50% until the year 2020 compared to the total emissions they had in 2005 (Ibid). The reduction should be achieved through the usage of alternative fuels, as well as better route planning and education programs in eco-driving (Ragn-Sells, 2012). Although Ragn-Sells was not collecting MSW in Växjö municipality when the goal was set, the continuous improvements regarding environmental impacts is part of their strategic work (General manager of Ragn-Sells Växjö, 2014-04-10).

Ragn-Sells is currently using RCV’s powered with Raspeed-oil Methyl Ester (RME) fuel, which emits lower levels of emissions. Both the municipality and Ragn-Sells have worked towards reducing the environmental impact of the MSWC, although it is still a
major issue which needs more attention (General manager of Ragn-Sells Växjö, 2014-04-10; Head of Växjö’s waste department, 2014-04-11). The major improvement areas regarding emissions are the rural parts of the municipality since the distance between the bins can be long. Additionally, the MSWC generates high emissions in the urban areas because of the higher quantity of bins and numerous stops to collect the bins (Head of Växjö’s waste department, 2014-04-11).

Besides emissions, other environmental impacts come from the RCV’s such as noise, odour and congestion (Head of Växjö’s waste department, 2014-04-11). Even though the noise generated from the RCV’s has been improved by implementing more quiet engines, it could be further optimized. The other environmental impacts are especially noticeable in the urban areas (General manager of Ragn-Sells Växjö, 2014-04-10).

1.2.3 Municipal Solid Waste Collection Cost Issues

According to the head of Växjö’s waste department, (2014-04-11) the geographically spread location between the bins in the rural areas presents challenges towards managing and planning the collection of MSW at the lowest cost. The driving distance between bins in the rural areas is quite high, which results in a more time consuming collection of bins as well as higher collection costs. Consequently, collecting a bin in the urban areas is less costly than collecting a bin in the rural areas. Not only because of the lower distance between the bins, which lead to less fuel and maintenance costs per bin, but also because of the achieved economies of scale in the urban areas, since the RCV can collect more bins within the same amount of time spent in the urban areas than in comparison to the rural areas (Head of Växjö’s waste department, 2014-04-11).

Another concern regarding MSWC costs is the fact, that the current route planning system calculates collection routes based on an average estimate where the bins are 75% full, as stated by the General Manager of Ragn-Sells Växjö (2014-04-10). Moving bins that are only partially full seems an unnecessary and avoidable misuse of resources, which presents improvement possibilities for reducing MSWC costs.

1.2.4 Constraints Of Changing Municipal Solid Waste Collection

Projects in MSWC in Växjö municipality is based upon the willingness of the political
party that is empowered (Head of Växjö’s waste department, 2014-04-11). It is the politician’s responsibility to determine how they might be involved in the field of MSWM and to plan an investment budget that might be available to Växjö municipality’s waste department (Ibid). According to the head of Växjö’s waste department (2014-05-08), the next local elections will be determinant for the decision-making. Moreover, the politicians believed that the implementation of new projects result in an increased MSWC fee, and thereby, the inhabitants might react negatively which could affect the politicians reputation. Nevertheless, the politicians are misjudging the situation and a rather small rise of the fee might not change the citizens’ mentality and behavior towards generating MSW, as stated by the head of Växjö’s waste department (2014-04-11).

Furthermore, the head of planning department in Växjo (2014-04-24) affirmed, that the city is in expansion which results in significant socio-demographic changes. Any improvements in Växjö municipality’s current MSWC need to be in alignment with the fast development of the city (Head of Växjö’s waste department, 2014-04-11).

1.3 Research Questions

Based on the background and problem discussion, four research questions can be formulated:

**Research question 1:** How can the municipal solid waste collection in Växjö municipality be improved through an optimized route planning?

**Research question 2:** How can Växjö municipality and Ragn-Sells AB reduce the environmental impacts of the municipal solid waste collection by optimizing the route planning?

**Research question 3:** How can Växjö municipality reduce their municipal solid waste collection costs by optimizing the route planning?

**Research question 4:** What are the constraints when changing the municipal solid waste collection in Växjö municipality and how can they be overcome?
1.4 Purpose

The purpose of this thesis is to examine and identify how the current MSWC of the municipality of Växjö can be improved through an optimized route planning. The thesis will show how the recommended changes enable the municipality of Växjö and Ragn-Sells to reduce the environmental impacts. In addition, the aim is to highlight how Växjö municipality is able to reduce their MSWC costs by optimizing the route planning. At last, the constraints of the suggested improvements for the MSWC in Växjö municipality are highlighted in order to overcome them.

1.5 Limitations

The main focus of this thesis is on the collection of Växjö’s MSW, performed by the transport company Ragn-Sells. Ragn-Sells is a large Swedish company within the recycling industry and the focus will be on their subsidiary in Växjö municipality. As already mentioned in the background, MSW collected by Växjö municipality includes waste from households, commerce and institutions. The collection of waste from construction, demolition and municipal sewage is not part of this thesis.

As described, the municipality has eight recycling centrals positioned around the municipality where the customers can dispose bulky, garde, hazardous and electronic waste. The collection of the waste at the recycling centrals will not be discussed in this thesis.

In addition, specific descriptions of the technical equipments used in the collection of MSW will be limited since the focus is on the route planning instead of the function of the technological devices. However, a brief overall description of those devices will be presented and illustrated with the help of pertinent figures.
1.6 Outline Of The Thesis

The structure of this paper followed eight chapters as figure 1 illustrates. Each number represents a single chapter of the thesis.

Figure 1: Disposition of the thesis

Source: Composed by authors.
In more details, figure 2 shows how the eight chapters of this paper thesis are combined to each other to develop the final conclusion.

Figure 2: Detailed outline of the thesis
2 Brief Information About Växjö’s Municipal Solid Waste Management

This chapter presents brief information about Växjö’s MSWM and their different actors. Then, Växjö’s MSWM strategy is explained followed by the presentation and illustration of the supply chain. The aforementioned information are not analyzed in the analysis chapter. However this chapter presents an essential outline of how the MSWM is handled in Växjö municipality.

2.1 Växjö’s Municipal Solid Waste Management

The waste plan in Växjö municipality is still based on wasteplan 1992 (Växjö kommun, 1992), in which the main goals were to increase environmental policies towards MSWM, conserve natural resources and offer a reliable and affordable sanitation to the customers. According to the head of Växjö’s waste department (2014-04-11), since the Waste Plan in 1992, the municipality has been able to fulfill the waste necessities throughout the years. Nevertheless, he affirmed that nowadays, due the obsolescence of the Waste Plan from 1992 (Ibid), decision-making has been managed spontaneously. Moreover, he expressed that over the years, the environmental, social and economical challenges towards managing MSW have increased and that the municipality of Växjö need a strong plan to accurately cope with the current necessities (Ibid).

In response to this obsolescence, the head of Växjö’s waste department (2014-04-11) expressed that by the summer of 2014 the new waste plan will be presented and will replace the first management plan established in 1992. With the new management plan, the Växjö municipality will set up MSWM guidelines for the next seven years. Also, a reconciliation of this plan might take place in 2017. The purpose of the management plan is that it should contribute to the national and regional environmental objectives, inform the public and various activities on planned changes and provide policymakers an overview of waste management with the opportunity to operate it. This management plan recognizes orientation objectives for the year 2020 and prioritizes the following target areas: increase in material and energy recovery from waste, reuse waste planning and the long term goal to prevent and reduce waste by 2020 (Ibid).
In addition to the local waste plan, Växjö municipality is following the EU waste management hierarchy that the European commission framed. Figure 3 illustrates graphically the current situation of Växjö’s MSWM according to the EU waste management hierarchy (Head of Växjö’s waste department, 2014-04-11).

Figure 3: Växjö’s MSWM according to the EU waste management hierarchy

![Graph showing EU waste management hierarchy]

Source: Composed by authors based on Avfall Sverige (2013).

Through the policies from the Waste Plan, the first step of this hierarchy, landfill, decreased to 1% by 2010 (Växjö kommun, 2014b). For the second step, energy recovery, Växjö municipality achieved a 49% recovery of the total waste in 2013. Waste is used to produce electricity, steam and heating for buildings, as well as biogas as a fuel for the city buses (Växjö kommun, 2014b).

The first step to achieve with the planning agenda in Växjö’s Waste plan for 2014-2020, will be the reuse phase (Head of Växjö’s waste department, 2014-04-11). The municipality is aiming for the repeating use of products and components for the same purpose for which the municipality conceived them. An example for this reuse goal, is the cooperative project called Macken (Ibid). Macken is a facility with its own reception on Norremarks recycling central in Växjö where people can submit products and materials for reuse (Macken.coop, 2014).

The additional step that will be prioritized through the Växjö Waste Plan 2014-2020, is
the highest EU stair: Waste Reduction (EuropeanCommission.eu, 2014; Växjö kommun, 2014b). Resource efficiency is one of Växjö’s future strategies in alignment with the European Commission initiative for a smart and sustainable MSWM (Ibid). Moreover, the head of Växjö’s waste department (2014-04-11) affirmed that by receiving the waste and preparing the material for reuse, it might increase the recycling of MSWM and decrease the new production, which in turn leads to increasing resource efficiency.

2.2 Supply Chain Of Solid Waste Management In Växjö

The collection and treatment of Växjö’s waste is separated into different phases and involves several parties, which is graphically illustrated in the following figure 4.

As shown in figure 4, around 42% of the total (kg/Inh-year) is collected by Ragn-Sells (Växjö kommun, 2014b). 40% represents bulky, garden, hazardous and electronic waste, which the customers bring to the different recycling centrals. For the remaining 12% of waste, the producing companies are responsible for collecting, transporting, and
reusing or abolishing the materials (Head of Växjö’s waste department, 2014-04-11). The producers offer 65 recycling stations (environmental houses) distributed all over Växjö in which colored and clear glass, metal, soft and hard plastic, paper, newspapers and batteries are recycled (Växjö kommun, 2014b).

As Appendix A illustrates, from the MSW that is collected by the municipality 50% is recycled, 49% incinerated and only 1% is landfilled (Växjö kommun, 2014b). The collected waste at the recycling centrals is distributed to different treatment facilities. In relation to the type and nature of the waste, a different recycling process is followed. The treatment of waste is usually carried out by contracted treatment facilities (Växjö kommun, 2014b).

The mixed waste that is retrieved from all properties is about 155 kg/Inh and per year (28%) and is transported to an incinerator facility (Växjö kommun, 2014b). At this facility, waste is converted into energy for district heating (Växjö kommun, 2013a). The incineration power plant Ljungsjöverket is owned by the Ljungby Municipality (Växjö kommun, 2014b). Approximately 75 kg/Inh of food waste is collected separately and transported to a biogas production (Växjö kommun, 2014b). This facility is in Häringetorp and the produced biogas is used as an alternative fuel for city buses (Växjö kommun, 2013a). Those two kinds of waste, mixed and food, represents the MSW which is collected by Ragn-Sells (General manager of Ragn-Sells Växjö, 2014-04-10).
3 Methodology

The purpose of this chapter was to present how this thesis was conducted. Therefore, the scientific perspectives were explained followed by different research methods. The authors explained the scientific approach and its concepts. Furthermore, different types of case studies were highlighted and the sampling methods presented. In addition, the data collection was described as well as the ethical aspects followed by the analysis method and the scientific quality. Finally, two graphs summarized the methodological approaches of this thesis.

3.1 Scientific Perspective

There are two main scientific perspectives with fundamental differences of how to study the reality: positivism and hermeneutics (Andersson, 2004; Bryman and Bell, 2011). Both perspectives are concerned about understanding a phenomenon through two different lenses, as stated by Cohen, et al. (2011). Andersson (1979) drew a clear line between the two perspectives and claimed that the difference is not only related to the approach to a specific study but it is also a question about attitude to life and how to view the world.

3.1.1 Positivism

Positivism is a perspective that requires an objective study with a hypothesis which is objectively tested (Bryman and Bell, 2011). Positivism attempts to achieve objectivity, measurability, predictability, and controllability as shown by Cohen, et al. (2011). Investigators that are using the positivist approach can select from a variety of traditional options, such as surveys, experiments and observations to explain the behaviour, generate knowledge, understand causes and generalize the specific findings (Ibid). The research is independently conducted from the outside (Saunders, et al., 2012). In general, data collection is highly structured and just an observable phenomenon can present reliable data and facts (Ibid).

In addition, the research is supposed to provide an absolute truth without any interpretations (Bryman and Bell, 2011) by showing the reality through mathematical and logical structures (Andersson, 1979). Cohen, et al. (2011) presented a similar interpretation, that positivism is an abstraction of the reality, achieved through
mathematical models and quantitative analysis. The positivistic perspective is used in medium large-scale research and should be examined by the models of natural science as explained by Cohen, et al. (2011) and Saunders, et al. (2012).

3.1.2 Hermeneutics

The second scientific perspective, hermeneutics, aims to interpret the reality (Åge, 2011). A hermeneutics study does not try to create an absolute truth since the perspective claims that there is no truth, while people interpret the reality differently (Ibid). Bryman (2012) stated, that hermeneutics is a method, which was originally formulated to understand or interpret texts. When analysing the text, the meanings of this text have to be highlighted from the author’s point of view (Ibid).

According to Patel and Davidson (2003), the hermeneutic scientists claimed that the reality cannot be quantified and measured, which is the reason why the scientists should subjectively interpret the reality. In particular, the scientists gained a profound understanding of the human behaviour by interpreting the meaning of interactions, actions, objects, and what these meanings have for individuals (Hesse-Biber and Leavy, 2010; Brymann and Bell, 2011). However, the only method to become familiar with social reality is from the standpoint of the involved individuals (Ibid). A similar interpretation is given by Cohen, et al. (2011), that the hermeneutic method attempts to understand and interpret the world with respect to its actors, which is why meanings and interpretations are crucial. It can be concluded, that recent scientists regard hermeneutics as an approach that interprets texts and social actions, as well as other non-documentary phenomena (Bryman, 2012).

3.1.3 Scientific Perspective Of This Study

The study conducted in this paper aims to suggest improvements for the MSWC in Växjö. The positivist would argue that the study could be quantified and proved through efficiency measures. The perspective of this study is that no absolute truth can be proven regarding the study. There are too many aspects to control and measure, which could affect the result of the suggested system. After improving the MSWC, costs effects and environmental impacts could be reduced. However, different people can interpret the effect of a new system for MSWC in many ways and the achieved
improvements can be the results of other reasons. Consequently, the scientific perspective of this study is hermeneutic.

3.2 Research Method

There are two basic research methods, which are the quantitative approach and the qualitative approach explained by several authors (Bordens and Abbott, 2013; Graziano and Raulin, 2013; Kothari and Garg, 2014). Choosing a proper research method depends on the purpose of the study and how the collected information will be analyzed (Bryman and Bell, 2011).

3.2.1 Quantitative

The quantitative research is an appropriate method when the empirical data can be measured or assessed numerically and expressed in mathematical terms (Bordens and Abbott, 2013). This method depends on the quantitative measurements of certain characteristics and is used to examine a phenomenon (Kothari and Garg, 2014). Different forms of surveys and interviews can be used in a quantitative research to gather data (Ibid). Bryman and Bell (2011), state that the quantitative research method usually implies a positivistic perspective and a deductive approach to the relationship between theory and research, while the emphasis is on testing theories (Ibid).

3.2.2 Qualitative

Qualitative research enables to analyze data from direct fieldwork observations, in-depth interviews, open-ended interviews, focus groups and written documents such as questionnaires (Björklund and Paulsson, 2003; Patton, 2005; Bryman and Bell, 2011) to be able to acquire a deeper understanding about a specific subject, event or situation (Bryman and Bell, 2011). A similar definition, given by Graziano and Raulin (2013), is explaining that qualitative research methods consist of observations, questionnaires, as well as analysing conversations and social networks. Generally, qualitative researchers focus on studying real-world settings inductively to provide deep descriptions and conduct case studies (Patton, 2005). In other words, the qualitative research approach emphasizes words rather than quantifications when it comes to gather and analyze data (Bryman, 2006; Bryman and Bell, 2011).
However, Bryman and Bell (2011) concluded, that it is important to be careful when separating the two research methods, since the situation in reality could be more complicated while a combination of both research methods might be the most appropriate solution.

### 3.2.3 Research Method Of This Thesis

Regarding this thesis, the authors mainly applied the qualitative research method. As described later on, the paper is based on data collected from several interviews, observations and secondary sources. The qualitative data gathered were applied to identify the main issues regarding the MSWC in order to suggest further improvements. Quantitative data were collected and used in this study to support the arguments, although the reliability of the data is not high as will be discussed later. Additionally, there was a limited access to certain data such as current emissions in Växjö municipality MSWC and equipment and installation costs of the proposed sensor technology. Therefore, a combination of both, the quantitative and qualitative research method was used for this thesis.

### 3.3 Scientific Approach

The scientific approach expresses the relationship between theory and reality (Bryman and Bell, 2011; Graziano and Raulin, 2013). Scientists usually apply the rational methods of induction and deduction (Graziano and Raulin, 2013). A third scientific approach is given by Svennevig (2001), which is the abductive approach.

#### 3.3.1 Deductive

According to Bryman and Bell (2011), deduction is the most frequent approach for the connection between theory and research. The deductive research approach is based on a deductive way of reasoning that moves from a general premise to a more specific conclusion (Anderson, 2002). In particular, hypotheses are deduced from theory, which are then converted into operational terms to define how data will be collected (Bryman and Bell, 2011). This approach is commonly known as top down approach. This means that the deductive approach is testing the theory (Ibid).
3.3.2 Inductive

Inductive approach generates theory directly out of the data. (Strauss and Corbin, 1998; Hesse-Biber, 2010) Induction is the type of research which moves from specific observations to formulate new theoretical bases that can be explored and finally end up developing broader generalizations and theories (Burns and Grove, 2005; Elo and Kyngäs, 2008). This approach is commonly known as bottom up approach (Ibid). In other words, the inductive approach is generating theory as explained by Bryman and Bell (2011).

3.3.3 Abductive

The use of abductive process generate the most accurate hypothesis formation within scientific processes (Reichertz, 2004). Abduction is used to find the likeliest possible explanation from the data collected (Ibid). Abductive research generates the most feasible decision-making with the information available, which is often incomplete (Flick, et al., 2004). Abduction is also known as hypothesis formation and happens when research during data analysis, generates beliefs or theories about the meaning or significance of their data on non-inductive and non-deductive grounds (Boutilier and Beche, 1995).

3.3.4 Comparison Between Approaches

The main differences between these three approaches is that the abductive approach generates hypothesis formation about the meaning of their data on non-inductive and non-deductive grounds (Boutilier and Beche, 1995). Inductive research is concerned with the generation of new theory emerging from data and deductive approach is aimed and done to test theory (Hesse-Biber, 2010). Abductive research differ since the data is insightfully abducting and there is a fair guessing about the meaning of data (Svennevig, 2001). While the deductive approach is commonly known as top down, inductive prefer to generate their own concepts in a bottom up manner (Blaikie, 2010).

3.3.5 Scientific Approach Of This Thesis

In the beginning phase of the study, the focus was on existing theory about the subject. The aim was to apply the existing theory to the MSWC in Växjö municipality,
therefore, no new theory was created. This approach excluded both inductive and
deductive approaches and is thereby strictly deductive.

Deduction follows a top down approach, thus this paper starts with the theory about
MSWC which generates a hypothesis for a solution of the problems. The study objects
were observed for being able to improve the MSWC in Växjö municipality by
optimizing the route planning. The analysis was conducted to confirm the suggested
approach and answering the stated research question. Figure 5 shows the top down
approach.

Figure 5: Deductive "top down" approach

Source: Composed by authors based on Blaikie (2010).

3.4 Case Study

3.4.1 Types Of Case Studies
Yin (2014) stated that a case study research is one of several forms of social science
research (others consist of experiments, surveys, histories, and archival analyses). It
provides the researcher with a holistic understanding of a problem, issue, or
phenomenon within its social context and presents a complex understanding of the
subject of question (Hesse-Biber and Leavy, 2010). A similar definition is given by Yin
(2014), where the case study investigates a contemporary phenomenon (the case) in its
real-world context. A basic case study contains a detailed and intensive analysis of a
A case study has to be focused on a bounded case (Bryman and Bell, 2011) and if the investigated phenomenon is not bounded enough, it is not a case (Merriam, 1998). This occurs when there is no end to the number of people involved, and to the time and number of observations that are performed (Ibid). However, the focus of a case study is on a process instead of outcomes, on context instead of a specific variable, on discovery instead of confirmation and the gained insights can directly affect policy, practice, and future research (Ibid). Several methods to collect data about the case exist, such as interviews, observations and document analysis, and they depend on the case and the used research questions (Hesse-Biber and Leavy, 2010).

Three different types of case studies can be defined according to their different purposes (Yin, 2014): First, exploratory case studies with the purpose to create hypothesis; Second, descriptive case studies with the purpose to demonstrate and illustrate a case; Third, explanatory case studies with the purpose to analyze complex systems with the help of a causal explanation (Ibid). What they have in common is the main objective to create an in-depth understanding of a specific topic, institution or system to create knowledge and to inform policy development, business practice and community action (Simons, 2009).

Yin (2014) stated that in cases where the main research questions are "how" or "why" questions a case study research is the preferred approach. Both qualitative and quantitative methods can be applied in a case study (Hesse-Biber and Leavy, 2010). According to Bryman and Bell (2011), case studies with qualitative research methods are preferred, since they are viewed as especially supportive when creating a comprehensive assessment of a case.

The main advantage of a case study is, that the investigation of a contemporary phenomenon is done in its real-world context (Yin, 2014). Additionally, George and Bennett (2005) identified that case studies are precisely, can achieve high conceptual
validity, have solid procedures to develop new hypotheses, and can address causal complexity. However, disadvantages include the issue of reliability and generalizability, which means that the result of the case study cannot guarantee that the phenomenon is common among other organizations (Merriam, 1998).

3.4.2 Case Study Of This Thesis

This study investigated a phenomenon that focuses on a bounded system. The number of people involved and the time was limited, which means that the phenomenon is bounded enough and is therefore a case. Furthermore, three of four research questions of this thesis are "how" questions and consequently the case study approach was the most suitable option of research method. Several methods to collect data about Växjö’s MSWC where used, such as personal interviews, observations, mailing of questionnaires and document analysis. The main purpose of the research questions was to create and develop hypotheses about the MSWC for Växjö. Hence, the explorative case study type was used.

3.5 Sampling Method

3.5.1 Population

Ghauri and Grønhaug (2005) explained, that after defining the research problem and developing a proper research approach, the following step in the research process is to decide on those elements from which the information will be gathered. This can be done by collecting information from each member of the population or by collecting information from a part of the population and taking samples from the larger group (Ibid). Accordingly, a population is the larger group of all people or objects of interest (e.g. nations, cities, regions, firms, etc.), whereas a sample is a smaller segment of the population that is selected for investigation (Bryman and Bell, 2011; Graziano and Raulin, 2013; Levy and Lemeshow, 2013).

3.5.2 Sample

After deciding on the population and the sampling frame, a sampling procedure has to be selected (Ghauri and Grønhaug, 2005). The procedures can be divided into two major categories, which are probability and non-probability samples (Bryman and Bell,
2011; Levy and Lemeshow, 2013). Probability sampling methods are mainly used in quantitative research (Graziano and Raulin, 2013) and randomly select a sample (Bryman and Bell, 2011). Non-probability sampling, in contrary, selects a sample that has not been randomly selected (Ibid). Ghauri and Grønhaug (2005) stated, that non-profitability samples are useful to gain insights into a phenomenon, primarily in qualitative research.

Ghauri and Grønhaug (2005) described three examples of non-probability samples: (1) In a convenience sample, objects that are convenient and relatively easy to obtain are selected. (2) In a judgement sample, judgement is used to get a sample that is representative of the population. This approach selects samples that help to answer the research question and is mainly used when working with a case study (Saunders, et al., 2012). (3) In a quota sample, certain subgroups of objects (e.g. small firms, intermediate firms and large firms) are represented in the sample in roughly the same proportions as they are represented in the population.

In summary, non-probability sampling is convenient, even though samples might not be representative of the population and lead to biased results (Graziano and Raulin, 2013). To describe valid inferences regarding the population on the basis of the sample, a probability sample should be used (Ghauri and Grønhaug, 2005). Selecting appropriate samples improves external validity and enables researchers to generalize their results (Graziano and Raulin, 2013).

3.5.3 Sampling Method Of This Thesis
Since this thesis is a case study and applies a qualitative research method, the non-probability sample procedure is used. The population in this study was the municipality of Växjö and Ragn-Sells in Växjö. A judgement sample procedure to select samples that are representative of the municipality and contractor were used. The head of Växjö’s waste department municipality and general manager of Ragn-Sells in Växjö were the selected samples for the study. In addition, the head of planning department in Växjö municipality was representing as a sample. All the investigated samples helped to form the research questions.
Additionally, the convenience sample procedure is applied, given the fact that the Linnaeus University is in Växjö and the examined municipality and transportation company are both in Växjö. This makes it easier to obtain necessary data and information about the collection of MSW.

### 3.6 Data Collection

According to Kothari and Garg, 2014, there are various ways of collecting appropriate data which differ in accordance with cost, time and other resources at the disposal of the researcher. There are two kinds of data which can be used in a research: primary and secondary data (Andersen, 2012). Primary data is collected specifically for the purpose of the study and can be collected through surveys, observations and interviews (Ibid). Secondary data on the other hand, can be collected through literature, and is created for a different purpose than the research in question (Björklund and Paulsson, 2003).

#### 3.6.1 Primary Data

The primary data can be collected through different ways such as observations, personal interviews, telephone interviews and mailing of questionnaires (Kothari and Garg, 2014). According to Graziano and Raulin (2013) and Kothari and Garg (2014), under the observation method the investigators can get information from their own direct observation without asking for a reaction from the respondent. This way, the data obtained are attributed to what is currently happening and if the observation is carried out accurately, hence, the subjective bias is eliminated (Ibid). Observation is a non-simulation technique since it observes the object in its normal state (Andersen, 2012).

On the other hand, the simulation technique is looking for a reaction from the object, which can be a reaction to a question or to a physical act (Andersen, 2012). Personal interviews are particularly suitable for intensive investigations since they are conducted in a face-to-face contact (Kothari and Garg, 2014). This method requires an interviewer that initiates the interview and collects the information from the interviewee (Ibid). Moreover, Kothari and Garg, 2014 described that a personal interview can be structured, semi-structured or unstructured. The latter authors explained that a structured interview has predetermined questions and an already decided order of them. For them, a semi-structured interview can have prepared subjects but the order and formulation
can differ. Finally, Kothari and Garg (2014) claimed that an unstructured interview contains no preparation, the questions are based on the current conversation. The telephone method is not very widely used and consists in collecting information by contacting respondents on the telephone (Kothari and Garg, 2014). The same authors mentioned that the collection of data through mailing the questionnaires to respondents is extensive since the respondents have enough time to give proper and thorough answers.

### 3.6.2 Secondary Data

According to Andersen (2012) but also Kothari and Garg (2014) secondary data are based upon theory information collected from previous research, which means that the data are already available. The same authors explained that secondary data can be either published or unpublished. Secondary data include process data, register data and research data. Process data is quantitative information that organizations register and is normally not available for the public (Andersen, 2012). Register data is also connected to information from the organization but is public through documentations such as annual and statistics reports. Research data is the theory collected from previous research (Ibid).

Bryman and Bell (2011) mentioned, that authors of secondary data could explain or interpret research results incorrectly or regard data from a single point of view. Additionally, the information in secondary data might not be complete and accurate (Ibid). However, secondary data offer an optimal starting point for the literature search, even though it should not be taken as a substitute for primary data (Ibid).

### 3.6.3 Data Collection For This Thesis

The primary data had a direct focus on the study objectives. The information was gathered through simulation and non-simulation techniques. Personal semi-structured interviews were held with Per Gunnarsson, the head of Växjö’s waste department and Gert Hansson, the general manager of Ragn-Sells in Växjö. Those interviews were semi-structured to clarify predefined questions but there was also a necessity to listen to the study objects concerns and inputs to the topic. A telephone interview was carried out with Petteri Maukola, the key account manager of Enevo, which is a company working
with technical solutions for MSWC. Moreover, primary data were collected from mailing of questionnaires to Herbertsson, the head of planning department in Växjö; Gunnarsson, the head of Växjö’s waste department; Hansson the general manager of Ragn-Sells Växjö and the key account manager of Enevo. Non-simulation techniques were conducted through observing the RCV driver using technology equipments installed in the RCV.

The theory gathered for this thesis was research data gathered from existing secondary sources. The data collected from the secondary sources has been created for a different purpose and different study objects, but they will give an understanding of the current topics being discussed. In addition, register data is used to complement the information collected from the interviews. Register data was collected from published documents by Ragn-Sells and Växjö municipality. In addition, process data was used and received from the head of Växjö’s waste department. The process data is presented later on in table 1.

Primary and secondary data was gathered from current actors in the market selling solutions for MSWC. Even though the sources are not reliable because of their agenda, the information was useful for benchmarking with the data collected in the theory chapter.

A possible weakness of this case study was the limited number of interviewees with insights about the MSWC in Växjö. The municipality and the contractor Ragn-Sells has a limited number of people working with the MSWC in Växjö. By contacting Ragn-Sells own consulting company based in Stockholm no further information could be provided due to the lack of experience within the investigated topic. Consequently, the possible number of respondents to the interviews was limited from the start. Although the respondents were few, they were both managers of their departments and had relevant information for this study. In addition to the interviews regarding the MSWC in Växjö, this thesis used a number of documents and observations that were conducted to complement the information. Table 1 shows the personal interviews, telephone interview, observation, mailing of questionnaires and process data used for this thesis.
3.7 Analysis Method

According to Yin (2014) it is important to have an analysis strategy when conducting a case study. Preferably, the analysis strategy should be defined before the research begins. After the strategy has been defined, an analysis technique should be developed (Ibid).
3.7.1 Analysis Strategy

Yin (2014) separated four different analysis strategies. The first strategy relies on (1) theoretical propositions, which means that the analysis should focus on the theory that will lead to a specific case study. This strategy assumes that the case study and the research questions have been based on those propositions, and thus, affect the data collection. The second analysis strategy is (2) a grounded up strategy, meaning that the data gathered should be analyzed to find patterns before paying any attention to theoretical concepts. This strategy is generally used in inductive research. In addition, the researchers are normally educated in the subject and thereby they already have certain concepts in mind (Ibid).

Developing a case description is the third strategy (3), which could be used if the two aforementioned strategies do not work. The researcher can have gathered all data without being able to define specific research questions. Similarly, the theoretical propositions could be done without being able to find useful concepts (Yin, 2014). The researcher should develop a framework which consist of different topics to the areas. The topics can be found by identifying gaps in concepts and weaknesses in other cases (Benbasat, et al., 1987). The fourth and last strategy (4) is examining plausible rival explanations and can be described as a combination of all the aforementioned strategies. When collecting the data, the researcher needs to consider other possible explanations and issues of the problem areas, which should affect the analysis (Yin, 2014). After the analysis strategy has been defined, the researcher can make a choice of five different analysis techniques (Ibid).

3.7.2 Analysis Techniques

Yin (2014) defined five different analysis techniques. The first technique is (1) pattern matching, which means that the findings from the case study are compared with the predictions made before the data collection. The second technique (2), explanation building, is a different type of pattern matching where the case study is developed and analyzed. The technique is mainly used in exploratory research and is used when there is a need to answer "how" and "why" questions (Yin, 2014). Thirdly, (3) a time series analysis means that the case study is analyzed through showing the development over time (Graziano and Raulin, 2013). The fourth technique is (4) a logic model which is
relevant for cases that investigates technology in change (Yin, 2014). It builds up a chain of events which has a cause-and-effect relationship with each other. This technique consists of matching events found in the empirical data with the theory to predict outcomes, therefore, it is a form of pattern matching. An organizational-level logic model analyzes events taking place in an organization and explains how changes can lead to improvements. There are also individual-level logic models which analyze a single person and a program-level logic model which is for studying possible results of a certain program, for instance a governmental program for reducing spreading of diseases (Ibid). The last technique is (5) cross-case synthesis which is strictly used for multiple case studies and for comparison between processes and events (Cohen, et al., 2011).

3.7.3 Analysis Methodology Of This Thesis

Regarding the analysis strategy, this thesis is developing a case description. Different areas in the topic have been studied and the research questions were divided into four parts. The route planning, environmental impacts, costs aspects and constraints. The topics were identified after finding gaps for the case and in the theoretical propositions.

For analysis technique, the logical model has been used. Specifically, an organizational level logic model was used when analyzing the case. Possible changes in the MSWC and the possible effects were explained through events. In addition, cause and effect relationships were showed in figure 19.

3.8 Ethical Aspects

3.8.1 Ethical Principles

There are a number of principles involving ethical aspects of a research. Some of the main principles for conducting a research are: the information consent, confidentiality and anonymity, use requirement and false pretenses (Bryman and Bell, 2011).

The information requirement means that the researchers have to inform the involved study objects about the purpose of the study and what different steps it involves. Consent requirement involves informing the study objects that their involvement in the study is optional and that they can interrupt the process at any time (Bordens and Abbott, 2013). Confidentiality and anonymity requires that any sensitive information
collected during the study will not be revealed and that the involving people in the study can wish to be anonymous (Cohen, et al., 2011). The use requirement means that the information gathered can only be used for the research in question and no other purpose. False pretense means that information given to the people involving the study cannot be false or misleading (Bryman and Bell, 2011).

### 3.8.2 Ethical Aspects Of This Thesis

Regarding the information requirements, the study objects were informed about the purpose and for what reason the information would be used. Since the study objects were asked if they are available for an interview, the consent requirement was fulfilled. Conviviality and anonymity could have been an important aspect to consider since the two study objects are in business with each other. Both shared the same information and did not share anything the other party was not aware about. The two study objects were also aware that both parties would be part of the study. The use requirement and false pretense were not an issue since the purpose of the study was clear for the study objects and the information was solely used to answer the research questions formulated for this thesis.

### 3.9 Scientific Quality

Yin (2014) stated, that the quality of an empirical research design can be judged according to certain logical tests. It is a rather complex and challenging task, in particular when it concerns a qualitative phenomenon (Kothari and Garg, 2014). To establish a high credibility and quality of the empirical case study research, four common tests are used (Yin, 2014), which are explained in the subsequent chapters.

#### 3.9.1 Construct Validity

This first test is primarily demanding in case study research, when it is necessary to create an effective set of measures and objective judgements to collect data (Yin, 2014). In general, validity is the effectiveness of measures and one of the most important concepts in research. It refers to the quality or precision of a study (Graziano and Raulin, 2013).
Construct validity tries to identify correct operational measures for the concepts being studied (Yin, 2014). It is complex and shows the degree to which results on a test can be based on the explanatory constructs of a sound theory (Kothari and Garg, 2014). Yin (2014) recommends three case study tactics to increase construct validity: First, using multiple sources of evidence to ensure validity during data collection; second, establishing a chain of evidence that is also relevant during the data collection phase; and thirdly, having the draft case study report reviewed by key informants.

3.9.2 Internal Validity

Internal validity is the ability of the research design to test the hypotheses (Bordens and Abbott, 2013). However, internal validity is primarily a concern for explanatory case studies to identify a causal relationship (Yin, 2014). Another concern over internal validity is the problem of making inferences (Ibid). A case study involves an inference when an event cannot be directly observed and the information is solely based on interviews or documentary evidence (Ibid).

3.9.3 External Validity

The third test handles the problem of knowing whether a study's findings can be generalized towards other studies, no matter what type of research method is used (Yin, 2014). According to Bordens and Abbott (2013), a study has external validity to the degree that its results can be extended beyond the limited research setting in which they were attained. Case studies rely on analytical generalization and issues may arise with the incorrect formulation of the research questions (Yin, 2014). When a case study has no pressing “how” or “why” questions, it is more difficult to achieve an analytical generalization (Ibid). Two main tactics can be used to increase external validity: using theory in single-case studies, and using replication logic in multiple-case studies (Ibid).

3.9.4 Reliability

The fourth test of reliability is demonstrating that the operations of a study, such as the data collection procedures can be repeated, with the same results (Yin, 2014), regardless of who does the case study (Graziano and Raulin, 2013). This means that a later investigator should achieve the same findings and conclusions (Yin, 2014). Yin (2014)
suggests two tactics to reach reliability: Firstly, using a case study protocol to manage the documentation problem; and secondly, the development of a case study database.

### 3.9.5 Scientific Quality of This Thesis

This thesis has high construct validity due to the fact that multiple sources of evidence, such as interviews, observations and documents, are used. High-ranking employees within the municipality of Växjö and the transportation company Ragn-Sells were interviewed during the data collection phase. Additionally, key informants from the university, the examiner and the tutor, continuously reviewed the thesis, which increased the construct validity.

The internal validity of this thesis is high because the first concern mainly affects explanatory case studies, while this case study is using the explorative approach. Additionally, false inferences were avoided by gathering information from multiple sources such as observations and documents to support the data obtained from interviews.

The results of this study could be generalized towards other Swedish municipalities, depending on certain circumstances such as a comparative geographical layout of the municipality. Nevertheless, the MSWC differs between different municipalities, which results in a low external validity. However, the research questions of this thesis started with a “how” formulation with increases the possibility to achieve an analytical generalization. Additionally, this single-case study is executed with the help of relevant theory, to increase external validity.

This thesis has a medium reliability, since the MSW collection at the municipality of Växjö continuously changes. Environmental regulations and the various trends in technology affect the findings and conclusions of future research. However, the thesis can be regarded as a protocol that handles the documentation problem in detail, since it describes the course of action and conclusions.
3.10 Summary Of Methodology

Figure 6 summarized the chosen methods for this thesis. It does not include ethical aspects since the work followed certain principles rather than making ethical choices.

Figure 6: Summary of methodology

Source: Composed by authors.
Furthermore, figure 7 highlights the chosen case study tactic to secure the scientific quality of this thesis.

Figure 7: Scientific quality

- **Scientific Quality**
  - **Construct Validity**
    - Using multiple sources of evidence
    - Interviewing high-ranking employees
    - Key informants continuously review case study report
  - **Internal Validity**
    - Use explorative case study approach to avoid cause-and-effect relationship
    - Avoiding false inferences by having multiple sources
  - **External Validity**
    - Use theory in a single-case study
    - MSWC differs from municipality to municipality
    - If similarities exist, results could be generalized
  - **Reliability**
    - MSWC continuously change and may affect future research
    - Trends in technology have an impact on future research
    - Use thesis as a form of case study protocol

*Source: Composed by authors.*
4 Theory Chapter

The theory chapter gathers information about the route planning in MSWC as well as deep data associated with the environmental effects and cost impacts of the route planning application. In addition, the political and socio-demographic constraints that affect the MSWM are described. The structure of the current chapter has been based on the four research questions to support the analysis. The research questions are as follow:

**RQ1:** How can the municipal solid waste collection in Växjö municipality be improved through an optimized route planning?

**RQ2:** How can Växjö municipality and Ragn-Sells AB reduce the environmental impacts of the municipal solid waste collection by optimizing the route planning?

**RQ3:** How can Växjö municipality reduce their municipal solid waste collection costs by optimizing the route planning?

**RQ4:** What are the constraints when changing the municipal solid waste collection in Växjö municipality and how can they be overcome?

Figure 8 illustrates a summary framework of the theory covered in this chapter. Overall, it shows the relation between the different theoretic subchapters and referred how these theoretic concepts are related to the research questions of this paper.

Figure 8: Theory framework

Source: Composed by Authors.
4.1 Route Planning In Municipal Solid Waste Collection

4.1.1 Vehicle Routing Problem

The traditional Vehicle Routing Problem (VRP) is an extensively studied problem in which the goal is to reduce the total cost of driving the vehicles from a depot to serve customers and afterwards return to the depot through optimizing route planning (Johansson, 2006). Additionally, the total travel distance should be minimized (Nuortio, et al., 2006). VRP refers to problems in order to determine an optimal design of routes for vehicle fleets aiming to satisfy geographically spread customers (Ibid). figure 9 illustrates an example of a VRP problem in the left side and a possible solution in the right side.

Figure 9: VRP example and possible solution

Several VRP’s that need to be considered when planning the route for MSWC are explained by Nuortio, et al. (2006), Kim, et al. (2006) and Faccio, et al. (2011):

The first problem, which is called Stochastic Vehicle Routing Problem (SVRP) is defined as a VRP where one or several components are stochastic by nature (Nuortio, et al., 2006). The same authors explained that the state of a stochastic component is random. They claimed that one of these stochastic components within MSWC is the lack of information towards the content and volume of the waste in each bin. For Nuortio, et al. (2006), the amount of MSW depends on multiple factors, including the
numbers of customers that are using a single bin at the same time, the demographic context and social behavior towards waste generation, seasonality and many others factors. Consequently, problems with MSWC can be categorized as a as stochastic problem (Ibid).

The second VRP is called, Capacitated Vehicle Routing Problem (CVRP), where the route planning is constrained by the capacity of the vehicle (McLeod and Cherrett, 2008). The volume and weight capacity that can be handled per RCV and per day is a typical parameter to consider (Kim, et al., 2006; Faccio, et al., 2011). The actual MSWC is carried out by RCV’s which compresses the waste collected (McLeod and Cherrett, 2008). Therefore, the capacity of the RCV’s is measured in weight since the waste is compressed by these self-compactors whereas the bin capacity is estimated in volume (Faccio, et al., 2011).

When the capacity of the RVC is reached, the driver needs to empty the tank at a disposal facility. Each RVC usually makes several disposal trips per day (Faccio, et al., 2011). Kim et al. (2006) stated, that in the majority of the literature, each RVC is assumed to depart from the depot, collect bins from only one route that has multiple stops, and return afterwards to the depot. One possibility is, to plan an initial route without considering disposal trips and then putting in disposal trips to the route. This implies the risk of the route feasibility, which is why this planning strategy is not recommended. Therefore, the disposal trips have to be considered at the beginning of planning the route, which changes the order of the bin collection (Ibid).

A third VRP of the collection of MSW is the Vehicle Routing Problem with Time Windows (VRPTW) explained by Nuortio, et al. (2006). Within this VRPTW a few or all customers have specific time windows in which the waste has to be collected (Ibid). Moreover, Li, et al. (2010) and Faccio, et al. (2011) explained that there is a route time limit per vehicle in which each RCV makes several disposal trips per day and when the vehicle attains the maximum daily distance covered, another RCV takes over. Kim, et al. (2006) described the time window constraint. For them, the considered time window concerns usually commercial waste collection but rarely residential waste collection, and typically refers to where and when the vehicle is supposed be unloaded during the shift. However, Faccio, et al. (2011) highlighted the time window constraint differently.
In fact, the authors referred to the term explaining that the vehicles have to respect a specific time frame with an imposed start time and finish time during the workday.

### 4.1.2 Real-Time Technologies

In general, VRP’s have been traditionally handled based on solutions with a static route planning, meaning that everything is planned in advance and the information does not change during the time (Ghiani, et al., 2003). Nevertheless, a more advanced society is leading to increase problems with the VRP of MSW and accordingly, static solutions for MSWC are no longer sufficient (Menikpura, et al., 2013). A new approach has emerged where VRP’s are handled according to a dynamic route planning in which the time variable has an important impact towards the route planning (Giaglis et al., 2004; Berbeglia, et al., 2010). In consequence, designing RCV’s routes are based on computer technologies with the ability to provide and gather real-time data during the MSWC (Berbeglia, et al., 2010). MSWC is supposed to include those technologies that are best applicable for a certain municipality (Menikpura, et al., 2013) and those that have the ability to provide real-time data for the implementation of an innovative and efficient MSW route planning (Faccio, et al., 2011; Islam, et al., 2014).

Real-time technologies can be divided in tracking systems, communication technologies, waste bin technologies and operation center software (Faccio, et al., 2011; Islam, et al., 2014), and will be explained into more details in the following subchapters.

#### 4.1.2.1 Tracking Systems

According to Arebey, et al. (2010), Global Position System (GPS) is a navigation system conducted by satellites, placed in the orbit to record locations on the earth. In fact, the satellites periodically emit radio signals to the GPS in order to calculate distance and to compute the position (Ibid). Today, GPS is used in motor vehicle’s to provide roadside assistance, determining the vehicle’s position that is displayed on an electronic map, and supporting drivers to keep track of their position (Ibid). In addition, the authors claim that GPS is an intelligent MSWC tool used for tracking the position of the truck and the bin location. It automatically navigates the route by giving turn-by-turn directions to designated locations (Arebey, et al., 2010; Hannan, et al., 2011).
Radio Frequency Identification (RFID) technology has emerged from the unknown into a mainstream high-tech tool and is a technology that enables automatic identification and data gathering through radio frequencies (RFIDJournal.com, 2013). This technology allows an automatic identification through electronic tags from a distance without requiring a battery in the tags; triggering a new wave of efficient and innovative business procedures (Preradovic and Karmakar, 2010; RFIDJournal.com, 2014). RFID technology is improving the monitoring and tracking of waste management, by providing a fast and reliable identification and data collection process. RFID applications in waste management can be installed in the vehicle and at the bin. In the vehicle, RFID readers are installed in order to identify the RFID tag of the bin (Abdoli, 2009; RFIDJournal.com, 2014). The main advantage to municipalities when using RFID in their route planning system is, that in addition to acting as a tool for improving operational efficiency with service verification and route optimization, it also acts as a tool to manage the contractor performance (Abdoli, 2009; Ali et al., 2012). The following figure illustrates the GPS and an RFID Reader both installed at an RCV.

Figure 10: Tracking systems

Source: Composed by authors.

4.1.2.2 Communication Technologies
As explained by Arebey, et al. (2010), communication technologies contain the Global System for Mobile communications (GSM) and the General Packet Radio System
(GPRS). The GSM is a digital mobile phone system that is broadly used in large parts of the world. This mobile technology uses a GSM network by searching a cell phone tower in the nearby area. Generally, the speed in which data is transferred is called the second-generation (2G) of wireless telephone technology (Arebey, et al., 2010).

On the other hand, GPRS is a developed wireless service from GSM and is associated with the Internet, shown by Arebey, et al. (2010) and Bamodu, (2013). GPRS enables mobile users to link with a data network. GPRS has a wide coverage and transfers information during MSWC to the operation center in real-time. Moreover, the GPRS communicates through a third-generation of wireless telephone technology (3G). The GPRS is compatible for both 2G and 3G systems (Ibid).

**4.1.2.3 Waste Bin Technologies**

There are several waste bin technologies used in MSWC, which are RFID tags, and diverse types of sensors and cameras that are mounted in the bin (Faccio, et al., 2011; Rada, et al., 2013). The RFID tags are attached to the bin and contain unique information about the household to which the bin belongs. When a RCV approaches to a bin, the RFID reader equipped at the RCV detect the RFID tag, identifies the bin and records the required information. Finally, this information is then transmitted to an operation center, explained by Hannan, et al. (2011). Cameras are usually mounted under the lid inside the bin, which enables monitoring the bin activities. The main function is to get images in collaboration with RFID readers and to estimate the type and quantity of waste inside the bin (Hannan, et al., 2011). Moreover, cameras allow the use of the image processing technique, in which the fill level of the bin is estimated by comparing a current image of the bin content with a previous image (Vicentini, et al., 2009).

Similar to the cameras, sensors are attached to the bin that monitor and detect the real-time fill level of the bin (Johansson, 2006; Patrícia, et al., 2010; Faccio, et al., 2011). The sensors are mounted under the lid and calculate the distance between the lid and the waste, as explained by Rovetta, et al. (2009). The following figure shows how RFID tags, cameras and sensors are installed at the bin.
4.1.2.4 Operation Center Software

The operation center software integrates the previously described technologies from tracking systems, waste bin technologies to communication technologies. Data is collected and the operation center software aggregates all information in order to optimize the MSWC (Arebey, et al., 2010). According to Faccio, et al. (2011), the main function of the operation center software is to monitor and analyze information transmitted and gathered from the RCV’s and bin technologies, in order to execute the two main activities: First, generating maps in collaboration with Geographic Information Systems (GIS), which enable the operation center software to design, and analyze maps. And secondly, generating an optimized route for the RCV’s according to the information provided from the GPS, GSM and GPRS (Ibid).

4.1.3 Route Planning Systems For Municipal Solid Waste Collection

The above described route planning technologies allow the implementation of an efficient RPS to be able to allocate resources, monitor processes, and gather information intelligently (Wang, et al., 2008; Faccio, et al., 2011). Consequently, MSWC costs as well as the environmental impacts could be reduced, while satisfying customers requirements (Ibid).
4.1.3.1 Route Planning Systems Using Cameras In Refuse Collection Vehicles

Hannan, et al. (2011; 2012) stated, that a number of forecast tools are required to estimate quantity of waste, optimize route planning and monitor RCV’s and bins. Hannan, et al. (2011; 2012) and Arebey, et al. (2010; 2011) developed RPS with cameras in RCV’s.

According to Hannan, et al. (2013), the MSWC begins with the driver being assigned with a specific RCV and a specific route. The driver turns on the black box controller, which activates the RFID reader, the camera, the GPS, the GSM and the GPRS in order to prepare the RCV for transmitting information to the control center system (Hannan, et al., 2013). The system is based on the wireless communication between the bins, the RCV and an operation center software, which is illustrated in figure 12. More detailed information of the communication framework between the RCV and the control center system is illustrated in Appendix I.

Figure 12: Solid waste collection system

![Diagram of solid waste collection system](image)


When the RCV approaches the bin area, the RFID reader identifies the RFID tag of the bin and the camera snaps a picture before and after the bin collection in order to estimate the waste of the bin (Arebey, et al., 2010; 2012; Hannan, et al., 2011; 2012; Hannan, et al., 2013). According to the authors, it is important to highlight that the RCV driver is responsible for the adjustment of the camera, to find the best direction for
taking a proper image of the bin and its surroundings (Hannan, et al., 2013). Moreover, the RCV personnel has to open the lid for taking the first image, and a second image ought to be taken when the bin has been emptied. The average fill level for each individual bin is estimated based on the previous captured images, which allows the route planning to be optimized (Arebey, et al., 2010; 2011; Hannan, et al., 2011; 2012; Hannan, et al., 2013).

According to Islam, et al. (2014), there are two core problems of using cameras within routing planning systems, which are the position of the camera to accurately process images, and the image processing method that integrates advanced methods of waste amount estimation, which is not in real-time.

4.1.3.2 Route Planning Systems With Sensors

Rovetta, et al. (2009), stated that the lack of real-time data inspired them to discuss an advanced RPS in which it was possible to monitor in real-time the waste fill level of the bins. Although, few researchers have studied this approach by the time (Saphores, et al., 2009), many municipalities and private companies started to introduce RPS with sensor to monitor bin fill levels (Rovetta, et al., 2009).

The first initiative was taken by the Swedish producers association, which equipped 3300 containers around the country with sensors and wireless communication equipment in order to estimate the level inside recycling containers (Johansson, 2006). As illustrated in figure 13, the sensor was mounted under the lid of the container. The sensor is activated once every hour and measures the level of the container. According to the fill level measured, an alarm is triggered in form of an automatic mail, which is transmitted through GSM and GPRS to the operation center software. A second alarm is sent in the same way when the sensor indicates that the container has been emptied (Johansson, 2006).
Johansson (2006) findings from this study were, that through this real-time technological equipment, the waste collection operations, scheduling and routing process can be optimized and monitored in a more efficient way. In addition, he claimed that the sensors led to changes from a static to a dynamic route planning, which lower operating costs, reduce labor hours, decrease transportation distances and lower number of bins collected. However, Johansson (2006) expressed that one of the main problems of this study is the fact that investment costs for the sensor technology are not considered. Additionally, the study limited the sensor application to recycling containers, rather than implementing the system in MSWC. Johansson (2006) also affirmed that besides the benefits of the system, many operators did not use this system and maintained their traditional static route planning.

Another way to handle RPS with sensor is presented by Faccio, et al. (2011). The real-time data, gathered through the sensors, enables to decide which bin should be collected and which should not. Faccio, et al. (2011) described the available real-time technologies, which can be seen in the following graph, to improve the collection of MSW. Additionally, software applications are developed to attain and manage real-time data, which is used for the suggested route planning system. Afterwards, the authors
Faccio, et al. (2011) introduced a new vehicle route planning system with the integrated real-time technology data, applied for the MSWC in an Italian city of around 100,000 inhabitants. The system is also validated, while simulating the findings and comparing the new system with other traditional routing systems (Ibid). In the end, an economical feasibility study is presented, which will be explained later on in the cost aspects chapter. The following figure 14 illustrates the technological framework used in the study of Faccio, et al. (2011).

According to Faccio, et al. (2011), it is important to consider the optimal replenishment level in RPS with sensors. The replenishment level is a percentage which shows the minimum fill rate the bin should reach before the software adds the bin to the route for collection. Johansson (2006) discusses a system where the sensors triggers an alarm when the replenishment level reaches 75% (yellow alarm) and 100% (red alarm). One possible route model would be to collect all the bins which have triggered the red alarm. In addition, the system would include all bins, which have reached the yellow level in the nearby area of a red alarm bin to the route (Ibid).
The suggested route planning system presents both economic and environmental benefits, stated by Faccio, et al. (2011). To be more precise, the route planning system enables to optimize the route plan and to decrease the covered driving distance as well as the number of RCV's employed. Consequently, a reduction of the travel time, the number of bins emptied, exhaust emissions, as well as noise and traffic congestion could be achieved (Ibid). However, according to Reverter et al. (2008), some sensors are strongly sensitive to humidity, which can represent a problem in the long term. Similarly, the authors expressed that some sensors are not compatible with the rest of the RPS. Patricia, et al. (2010) commented that some sensors could have problems with the weather and temperature which would require frequent cleaning.

### 4.1.3.3 Route Planning Systems With Sensors and Cameras

There have been research regarding RPS that combine both cameras and sensors (Vicentini, et al., 2009). The municipality of Pudong (Shanghai) developed a RPS called Clean Wings project. The project consisted of an intelligent RPS based on two main activities. Firstly, the bin monitoring of the waste in the collection point focusing mainly on early gathering of data about the waste in the bins. And secondly, the transmission of the information to the operation center software which maps, monitors and plans the route planning (Vicentini et al., 2009). Both activities are illustrated in figure 15.

Figure 15: Clean Wings Project Framework and flow of information

Source: Composed by authors based on Vicentini et al. (2009) and Rovetta, et al. (2009).
The key element of this project is the bin technology (Vicentini, et al., 2009). The bin technology is based on the combination of multiple sensors and one camera for image processing. The sensors are mounted on the top and in the bottom of each bin (Rovetta, et al., 2009).

As illustrated in figure 16, on the top of the bin a camera is attached with a sensor, which enables to collect information about the shape, the area and the height of the waste. In addition, a set of LED lights provide illumination and enables a more accurate volume estimation shown by Vicentini, et al. (2009). The bottom of the bin is equipped with a sensor which constantly scales the weight of the waste. Similarly, technology communications are installed, which provide the connectivity with the operation central software (Rovetta, et al., 2009).

Figure 16: Bin technologies in the top and bottom of the bin

![Bin technologies in the top and bottom of the bin](image)

Source: Composed by authors based on (Vicentini, et al., 2009; Rovetta, et al., 2009).

The main outcomes of RPS’s that combine sensors and camera is its possibility to monitor disposed waste in the bin in real-time and the ability to optimize the RCV route according to the bins content (Rovetta, et al., 2009). Moreover, this RPS provide real-time estimations of weight, type and volume of waste (Ibid). It is important to highlight that the potential accuracy of the multiple sensors in the core element of the Clean Wings project has been validated over several tests of the system in real conditions (Vicentini, et al., 2009).
According to Rovetta, et al. (2009) the main drawbacks of this framework are the lack of information towards the devices in the bin. The overall cost of the bin technologies is not taken into consideration in the study. Furthermore, Islam, et al. (2014), expressed that several problems occur with the usage of cameras for image processing systems, mainly due to the positioning to take the image and the real accuracy of the image in real-time.

4.1.3.4 Summary Of Routing Planning Systems

Table 2: Summary of route planning systems with camera on the RCV

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>System Technologies</th>
<th>Objective</th>
<th>System Benefits</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acobey et al., 2010</td>
<td>Traceability, RFID reader, GPS, Communication GSM/GRPS, Bin Technologies Camera (is on the truck), RFID, Central Control GIS</td>
<td>Optimize the RPS through estimating the fill waste level through RCV camera.</td>
<td>Improve waste collection performance, Use of camera image processing to estimate fill levels based on historical data.</td>
<td>Estimation of fill levels is not in real-time, Camera system has difficulties towards accurate positioning and image quality, The RCV drivers need to adjust the camera manually and point to the bin to take the image.</td>
</tr>
</tbody>
</table>

Source: Composed by authors.

Table 3: Summary of route planning systems with sensors in the bin

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>System Technologies</th>
<th>Objective</th>
<th>System Benefits</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johnson, 2006</td>
<td>Traceability, GIS, Communication GSM/GRPS, Bin Technologies Sensor, Central Control GIS</td>
<td>Optimize the RPS mounting in 3000 Swedish Recycling centers with sensors for estimating fill level.</td>
<td>Optimize the waste collection and improve the RPS in a more efficient way, Change from a static RPS to a dynamic RPS, Lower operating costs, lower labor of hours and the decrease transportation distances.</td>
<td>The study do not consider the cost of investment, The study is limited the sensor application within the recycling container, rather than implementing the system in MSW bins, Many operators did not use this system and maintained their traditional static RPS.</td>
</tr>
<tr>
<td>Pietro et al., (2011)</td>
<td>Traceability, RFID reader, GIS, Communication GSM/GRPS, Bin Technologies Sensor, RFID, Central Control GIS</td>
<td>Optimize the RPS performance with a new RPS with real-time data.</td>
<td>New routing model has economic and environmental benefits, Optimized route plan, Decrease covered driving, and number of RCV’s needed, Reduce travel time, number of fixed and unusual stops, exhaust emissions, noise and traffic congestion.</td>
<td>Define optimal risk parameter of bins, Define optimal replacement level parameter.</td>
</tr>
</tbody>
</table>

Source: Composed by authors.
Table 4: Summary of route planning systems with sensors and camera

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>System Technologies</th>
<th>Objective</th>
<th>System Benefits</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traceability GPS</td>
<td></td>
<td>• Monitor every time waste is disposed in the bin and provide estimations of the</td>
<td>• The main drawbacks is the lack of information towards the bin technological setup.</td>
</tr>
<tr>
<td></td>
<td>Communication GPRS</td>
<td></td>
<td>weight of waste, type of waste and volume.</td>
<td>For image processing systems the positioning of the camera is a big challenge. In the same way, the image processing technique is not always in real time.</td>
</tr>
<tr>
<td></td>
<td>Bin Technologies</td>
<td></td>
<td>• The data collected provide the operators the possibility to monitor the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scissor (distance)</td>
<td></td>
<td>information and optimize the RCV routes in alignment to the container content.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Camera</td>
<td></td>
<td>• The accuracy of the set of sensors in the core element of the Clean Wings project has been validated over several tests of the system in real conditions.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LED Lights</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Sensor (Weighting)</td>
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<tr>
<td></td>
<td>Central Control GIS</td>
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<tr>
<td>Rovens et al., 2009</td>
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<td>Vicentini et al., 2009</td>
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Source: Composed by authors.

4.2 Environmental Impacts

4.2.1 Environmental Impacts From Municipal Solid Waste Collection

As mentioned, the slow speed and numerous stops made by the RCV’s lead to high rates of emission (Bing, et al., 2014). According to Bogner, et al. (2008) the waste industry was responsible for 3-4% of all green gas emissions in the world, which are the emissions contributing to the greenhouse effect. Friedrich and Trois (2011) claimed that the major improvements should be done in developing countries, although there are improvements to be made all over the world. In the European union, the figures were similar to the rest of the world with 3% greenhouse emissions coming from the waste sector (Punkkinen, 2012). Friedrich and Trois (2011) pointed out that there has been a lack of interest on studying emissions from MSWC, instead the focus has been on landfilling and disposal. The main greenhouse gas emitted from MSWC is carbon dioxide, although there other kinds of harmful greenhouse gases, which are not widely discussed such as nitrous oxide and methane (Ibid). The other emissions are normally not taken into account when conducting studies about the effect of MSWC on the environment since carbon dioxide is the main contributor to the greenhouse effect (Eisted, et al., 2009).
Heavy duty vehicles are usually using diesel engines that have high rates of emissions and high rates of air pollution, and can threaten individual health. Recent studies showed that carcinogen which is emitted from diesel can lead to cancer. As a result of the drawbacks with diesel engines, several heavy duty vehicles, especially those used in cities are using alternative fuels. RME is a fuel produced from rapeseeds, which is commonly used in heavy duty vehicles (Jalava, et al., 2012). An engine running on RME uses 15% more fuel than an diesel engine even though it has less emissions (Hassaneen, et al., 2012). In particular, the fuel has 50% less carbon dioxide emissions compared to diesel, although the fuel cannot work below -10 degrees celsius. If the temperature is below this, the fuel needs to be blended with diesel (Stockholms Stad, 2008). Another advantage with RME is that it has lower rates of other harmful emissions such as carbon monoxide, hydrocarbon, nitrogen oxides and particulate matter (Jalava, et al., 2012).

Besides emissions, Larsen, et al. (2009) described additional environmental impacts to consider in MSWC such as noise and odour. Aranda Usón, et al. (2013) discussed the same topic and mentioned congestion, noise and odour as other environmental impacts. Punkkinen (2012) identified the same environmental impacts but claimed that they cannot be quantified and therefore, it is difficult to study the exact effects a more efficient MSWC would have on them. According to Faccio, et al. (2011), traffic congestion and noise issues resulting from the MSWC are more common in urban areas because of the numerous stops and already existing congestion.

4.2.2 Calculating Emissions And Fuel Consumption

According to Larsen, et al., (2009) a RCV passes several phases when collecting waste. It drives from the garage to the collection area, collects waste, drives to a treatment facility and unloads waste. After the last step, the RCV can either continue in the same collection area, drive to a new one or return back to the garage. Larsen, et al. (2009) used a formula to identify the amount of fuel consumption in the collection phase. In the example of the specific article, the diesel consumption is calculated in the formula below. $D_{\text{collection}}$ is the total diesel consumption for one tonne of waste collected. $D_{\text{total}}$ is the total diesel consumption. $D_{t, \text{empty}}$ is the diesel consumption when the RCV drives empty, from the garage to the collection area and from the treatment facility.
to the next collection area or to the garage. $D_{t, \text{full}}$ is the diesel consumption when the RCV is full and is driving from the collection area to the treatment facility. $M$ represents the number of tons collected (Larsen, et al., 2009).

Figure 17: Formula fuel consumption

$$D_{\text{collection}} = \frac{D_{\text{total}} - (D_{t, \text{empty}} + D_{t, \text{full}})}{M}$$


Sonesson (2000) conducted a study in Uppsala, Sweden. Table 5 shows the number of stops made by RCV’s during a year in a certain collection area. The study also contains information about distance driven for those stops, waste collected, fuel consumption and distance to treatment centers. For a similar amount of stops during a year, the rural areas had higher rates of emissions as a result of the greater distance driven (Ibid).

Table 5: MSWC information in different parts of Uppsala

<table>
<thead>
<tr>
<th>Area</th>
<th>Stops per year</th>
<th>Distance driven (km/year)</th>
<th>Waste collected (tonne/year)</th>
<th>Fuel consumption</th>
<th>Distance to treatment (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>49100</td>
<td>9000</td>
<td>2400</td>
<td>189000</td>
<td>4</td>
</tr>
<tr>
<td>Rural</td>
<td>48000</td>
<td>23000</td>
<td>1080</td>
<td>310000</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Composed by authors based on Sonesson (2000).

Larsen, et al. (2009) conducted a study where they compared the emission from MSWC in different parts of two municipalities in Denmark by measuring the amount of fuel that was required per ton of waste collected. They separated the municipalities to five areas: city, apartment buildings outside the city center, single-family houses in urban areas, small towns and rural areas. The results showed a range between 1,4 and 10,1 liters per tonne. Apartments outside the city center had the lowest emissions because of the easy access to the bin and high rate of waste per pick up. It was closely followed by city areas and single family houses in urban areas. Small towns and rural areas had the lowest points of fuel efficiency as a result of the long driving distances (Ibid). Table 6 shows the results of the study.
4.2.3 Environmental Impacts From Optimized Route Planning

As Nuortio, et al. (2006) mentioned, RCV’s slow speed and numerous stops result in a high environmental impact. Apaydin and Gonullu (2008) stated that emissions emerging from RCV’s are proportional to route time and route distance. Emissions increase due to empty miles generated by the RCV. The shorter the distances driven by the RCV, the less the emissions are (Ibid). Iriarte, et al. (2009) conducted a study in Barcelona’s urban areas and concluded that there is a need to improve the efficiency of MSWC in urban areas to reduce the high environmental impacts (Iriarte, et al., 2009). The engine of the RCV’s are running while the bins are emptied and the RCV’s are normally stuck in traffic congestion in urban areas (Faccio, et al., 2011). As a result of that, the non-driving time in urban areas accounts for 50% of the total time. It causes high levels of emission, noise and traffic congestion which, according to the authors, result in a need for better route optimization (Ibid). As previously expressed, the emissions are even larger in rural areas because of the long distances and low volume of waste per bin (Larsen, et al. 2009).

There are several benefits of using RPS with sensors in MSWC. The major positive environmental impacts are fewer stops, minimized area covered and less RCV’s in use, which results in less emission in the whole municipality in addition to less congestion and noise in the urban areas (Faccio, et al., 2011). Zsigraiova, et al. (2013) conducted a case study in Barreiro, Portugal by improving the route optimization in the city’s glass waste collection. Instead of implementing sensors that, according to the authors, are more accurate but more expensive, they calculated an average fill rate for each

Table 6: Emissions in different parts of municipalities

<table>
<thead>
<tr>
<th>Municipality Parts</th>
<th>Diesel Consumption (L/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Center</td>
<td>3 – 3.1</td>
</tr>
<tr>
<td>Apartments, buildings outside city center</td>
<td>1.6 – 1.7</td>
</tr>
<tr>
<td>Single-family house in urban areas</td>
<td>3.3 – 3.6</td>
</tr>
<tr>
<td>Small Towns</td>
<td>2.4 – 5.7</td>
</tr>
<tr>
<td>Rural Areas</td>
<td>6.3 – 10.1</td>
</tr>
</tbody>
</table>

Source: Composed by authors based on Larsen, et al. (2009).
individual container using historical data collected through a GIS system. The method showed improved results in emissions compared to the old system. The study demonstrated that if the route was optimized the distance could be reduced by 28% and the time spent on the collection by 43%. In total, the optimized tour planning resulted in 40% less fuel consumption. Although the study was made on glass waste, the authors claimed that similar effects can be achieved for MSWC (Ibid).

4.2.4 Summary Of Environmental Impacts From Route Planning Systems

Table 7 presents the articles used in this theoretical chapter with different RPS and how they affect the environmental impacts. As presented, not all articles describe the environmental impacts of their suggested solutions. There is also a case with Hannan, et al. (2013) where they mentioned improved environmental impacts although they do not specify if they mean emissions or other environmental impacts, similarly, Vicentini, et al. (2009) who only discuss environmental conditions without specifying them. As mentioned above, Zsigraiova, et al. (2013) calculated the total fuel consumption saving in their study. No other article shown in the table specifies the amount of reduced emissions or fuel consumption.

Table 7: Summary of RPS solutions and their effect on environmental impacts

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Solutions</th>
<th>Environmental impacts from bin level sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Façcio, et al., 2011</td>
<td>Sensors</td>
<td>1. Decreased emissions, less congestion, lower noise</td>
</tr>
<tr>
<td>2. Johansson, 2006</td>
<td>Sensors</td>
<td>2. Reduced emissions, congestion and noise</td>
</tr>
<tr>
<td>3. Zsigraiova, et al., 2013</td>
<td>Improved route planning based on average fill rate</td>
<td>3. Reduced emissions</td>
</tr>
<tr>
<td>4. Arebey, et al., 2010</td>
<td>Camera on the RCV</td>
<td>4. -</td>
</tr>
<tr>
<td>5. Hannan, et al., 2011</td>
<td>Camera on the RCV</td>
<td>5. -</td>
</tr>
<tr>
<td>6. Hannan, et al., 2012</td>
<td>Camera on the RCV</td>
<td>6. -</td>
</tr>
<tr>
<td>8. Arebey, et al., 2012</td>
<td>Sensors and camera</td>
<td>8. -</td>
</tr>
<tr>
<td>9. Rovetto, 2009</td>
<td>Sensor and camera</td>
<td>9. -</td>
</tr>
</tbody>
</table>

Source: Composed by authors.
4.3 Cost Impacts

4.3.1 Municipal Solid Waste Collection Cost

The collection of MSW involves large expenditures, as stated by Faccio, et al. (2011), and often accounts for a considerable percentage of the total MSWM budget (Johansson, 2006; Tavares, et al., 2009). In fact, costs for the MSWC could represent up to 70% of the total MSWM costs, which mainly consists of fuel costs for the RCV's (Tavares, et al., 2009). The total percentage depends on the geographical location and fuel prices (Ghose, et al., 2006) and an increase of the MSW quantity would influence the collection with an expected rise in costs (Di Maria and Micale, 2013). However, municipalities are increasingly challenged to develop a sound budget without increasing the tax burden or reducing the service of the MSWC to the inhabitants (Rogge and De Jaeger, 2013).

Municipalities can use public resources to finance the MSWC (Rogge and De Jaeger, 2013). Typically, the municipality recovers costs from the users of the MSWC through a monthly payment or a variable fee (Batllevell and Hanf, 2008). It might therefore be of particular interest for the municipality to have an idea about the costs that occur and the cost efficiency realized in the collection of MSW, as explained by Rogge and De Jaeger (2013). As already defined in the background, efficiency refers to achieving the maximum output with the minimum input (Productivity Commission, 2013). In the case of cost efficiency, the inputs normally correspond to the costs incurred for offering the MSWC service (Rogge and De Jaeger, 2013). Measuring the cost efficiency of the MSWC depends on detailed data about the occurred costs, which is typically lacking (Ibid).

In general, as stated by Faccio, et al. (2011), waste collection is expensive to operate in terms of investment costs (such as costs for bins and vehicles) and operational costs (for fuel, and maintenances). Operational costs for fuel and oil consumption, as well as for the maintenance of the RCV, depend on the covered distance that is usually measured in terms of kilometres (km) (Ibid). Due to the low average speed, frequent starts and stops, and bin waste unloading operations; RCV’s have significant operation costs (Johansson, 2006). Additional costs arise, such as labour costs for the crew, which are costs for drivers and depend on the number of vehicles employed (Ibid). Normally, the
operational costs are measured in terms of cost per ton (Faccio, et al., 2011). Parameters such as the driving distance, the actual operating conditions of the vehicle (e.g. the engine), vehicle load and road gradient, influence the fuel consumption (Tavares, et al., 2009).

4.3.2 Equipment And Installation Costs
If a municipality decides to invest in a new RPS, several costs arise (Faccio, et al., 2011). Besides initial costs for purchasing the traceability equipment for bins, vehicles and the operation centre, installation costs occur. This could be for instance cost for installing the traceability equipment per vehicle, per bin and at the operation centre (Ibid). However, these investment costs result in possible savings, which are shown in the following chapter.

According to Rovetta, et al. (2009), costs for sensors have not yet been estimated because of the limited number of prototypes manufactured. Additionally, Rovetta, et al. (2009) concluded, that the sensors have to fit in to the existing bins used in the MSWC and that the sensor costs should be limited to a percentage of the total bin cost. In their study, the costs for sensors ranged between 20% and 30% of the total bin cost (Ibid). However, an example of costs for sensors to measure the content level of a waste or recycling bin are given by Colin Bell, managing partner and co-founder of the Vancouver based RecycleSmart Solutions Inc., which stated in an interview with "The Globe and Mail.com" that sensors cost between 250 and 300 Canadian dollar (Theglobeandmail.com, 2013) , which is converted into the Swedish Krona approximately 1.525 to 1.830 SEK (Xe.com, 2014).

4.3.3 Cost Effects From Optimized Route Planning
Currently, MSWM organizations are seeking to reduce the total cost of routing a number of RCV’s from their depots to the waste collection and treatment areas (Arebey, et al., 2011; Hannan, et al., 2012). Using the real-time data from a RPS with sensors would minimize the operating costs (Arebey, et al., 2012). As shown by Rovetta, et al. (2009) and Faccio, et al. (2011), the collected real-time data allows optimizing vehicle routes, with the purpose of minimizing collection costs and enhancing waste collection efficiency. Faccio, et al. (2011) demonstrated that a RPS with sensors could lead to a
reduction in investment costs for the RCV fleet, due to the ability to plan on-demand collections based on the effective need, with a resulting saving in the amount of vehicles. Moreover, a reduction in operational costs, such as fuel and maintenance, could be achieved, because of the decrease of RCV's, the decrease of the covered driving distance and the decrease of the number of bins emptied (Ibid).

Hannan, et al. (2012) came to a similar result, that using RPS with sensors would lead to a dynamic and efficient route planning, which will minimize the operating costs. Even though the study of Johansson (2006) examined the effects of the waste level sensors installed at recycling containers, they showed that cost reductions in the range of 10% to 20% could be expected. Investment costs in sensors have not been considered in their study (Ibid).

4.3.4 Economic Feasibility

As shown by Guerrero, et al. (2013), updating technological equipments have a positive effect on the MSWC even though it includes an economic burden for the municipalities. Sharholy, et al. (2007) and Sujauddin, et al. (2008) explained that significant expenditures are required to provide an efficient MSWC. The collection of MSW provides a fundamental public service and investments in this service do not necessarily require a justification in form of return on investment or profit margins, as stated by Ghose, et al. (2006) and Tavares, et al. (2009). Nevertheless, since MSWM is very cost-intensive, investments in MSWC have to be justified in form of environmental, technological and economic feasibility to realize the necessary degree of efficiency (Tavares, et al., 2009; Aranda Usón, et al., 2013).

Pires, et al. (2011) suggested a cost-benefit analysis, to identify positive and negative economic effects. The benefit models can consider environmental aspects and transform them into economic terms (Ibid). Another possibility to address the economic feasibility is given by Faccio, et al. (2011). They analyzed the operational costs as well as the installation costs and used traditional indicators for economic feasibility studies such as the payback period, which identifies how long is the period to refinance the initial investment. Different scenarios were created with the same basic conditions such as number of inhabitants or the biweekly collection of bins, but with different parameters such as the average waste level of the bin. However, the payback period is almost
always less than three years, just in one case where the parameters are extreme, the initial investment in real-time technologies is not refinanced within the first five years (Ibid). Faccio, et al. (2011) considered the following installation and annual costs when comparing the different scenarios:

![Table 8: Installation costs and annual costs](image)

Source: Composed by authors based on Faccio, et al. (2011).

### 4.4 Constraints Of Changing Municipal Solid Waste Collection

MSWM is increasingly a challenge for municipalities (Aranda Usón, et al., 2013). A number of conditions should be taken into consideration when it comes to dealing with MSWM, which include local legislation, policies and habits of the population (Rovetta, et al., 2009). MSWM has become a significant concern for municipal authorities due to the increasing generation of waste, the urban population’s rise and the changes in consumption patterns (Guerrero, et al., 2013; Marshall and Farahbakhsh, 2013). Improving MSWM has become a priority in urban communities worldwide (Wang, et al., 2012) but it is a complex mission requiring political decisions based on several parameters such as economic, environmental, technical and social issues (Tavares, et al., 2011).

#### 4.4.1 Political Challenges

According to Vidanaarachchi, et al. (2006), it is generally acknowledged that MSWM is the duty and responsibility of municipalities. Nevertheless, Moghadam, et al. (2009)
demonstrated in their study that politicians do not prioritize MSWM and have low willingness to get involved and implement services related to MSWM in comparison with other municipal activities. It is essential for the municipalities to make precise budget plans since the investment cost for MSWM projects might vary to a great extent because of political influence (Weng and Fujiwara, 2011).

The United States Environmental Protection Agency published, in 1990 a guidebook called “Sites for our solid waste”, which is mainly for public officials to improve the management of MSW (USEPA, 1990). In this guidebook, however, several political issues are specified, such as local elections and the controversial issues that are further complicated by politicians since MSWM programs require the support of influential political figures. According to USEPA (1990), establishing MSW projects may lead to additional development and thus, political parties are likely to be drawn into debates about how much improvements the municipalities should permit. This “Sites for our Solid Waste” guidebook explained that a local election is able to radically change the political complexion of a municipality. Moreover, the guidebook stipulated that the politicians who have enough concern about a MSW issue and devote time and energy to a project will, according to the USEPA (1990), always have more political impact than those who do not pay attention to the issue.

4.4.2 Socio-Demographic Challenges

Municipalities in developed and developing countries are focusing on MSWM due to its effects on the public concern for the environment and since improper MSWC places citizens at risk (Zamorano, et al., 2009). On the other hand, Sujauddin, et al. (2008) claimed that generating MSW will not cease growing in quantity and complexity and is affected by the family size, the education level, the monthly income and the attitude towards environment. According to Pandey (2012), the creation and composition of waste have been more varied due to the changes of lifestyles and consumption patterns. Furthermore, Rovetta, et al. (2009) mentioned that the demand for a sustainable environmental development of standards of living made the population expect major efforts from the local municipal authorities. Households attitudes towards sorting waste are influenced by the active support and investment of municipalities (Zhuang, et al. 2008) and the fee for the collection service (Scheinberg, 2011). In Sweden, the whole population has to sort their waste and several collection systems as well as sorting
programs have been developed locally in the municipalities (Dahlén, et al., 2007). Ramos, et al. (2012) addressed in a case study the benefits to the involvement of the municipality towards MSWC. The same authors explained that the inhabitants become a considerable part of the solution, and hence somehow, managers of the project. Finally, Ramos, et al. (2012) highlighted that the involvement of the municipality in MSWC enhance the social capital of the municipality, empower the municipality and increase local knowledge on MSWC. Sharholy, et al. (2008) suggested that the efficiency of MSWM depends upon the active participation of both the municipal agency and the citizens.

Budzianowski (2012), described in his study that the urbanization has become a worldwide trend which has brought incremental challenges in the MSW industry. Many local governments and urban agencies determined that MSWM has become an issue for their urbanization and economic development (Shekdar, 2009). The high population growth rate, the increase in income per capita (Pandey, et al., 2012), the rapid urbanization and the rise in community living standards have accelerated the MSW generation rate in terms of volume and variety since the beginning of the last decade (Minghua, et al., 2009). It is therefore important to optimize the MSWC (Beliën, et al., 2012). Moreover, the growing urbanization is complex and becomes a primary concern for local municipal authorities regarding the MSWC (Rovetta, et al., 2009). Therefore, there is a necessity to identify the socio-demographic factors on MSWM (Cherian and Jacob, 2012) in order to develop solutions which can handle the increase of waste generation and improve the MSWM efficiency (Yu-min et al., 2011; Liu, et al., 2013).
4.5 Integration of Theory

Figure 18: Integration of theory
4.6 Analysis Model

Figure 19, shows the connections between the different theoretical subchapters. This analysis model illustrates how the concepts work as a base line for the empirical data collection chapter as well as the analysis in order to respond to the research questions.

Figure 19: Analysis model

Source: Composed by authors.
5 Empirical Description

The empirical data chapter contains information about the municipal solid waste collection in Växjö municipality. The chapter has been followed the structure of the four research questions to support the analysis. The research questions are:

**RQ1:** How can the municipal solid waste collection in Växjö municipality be improved through an optimized route planning?

**RQ2:** How can Växjö municipality and Ragn-Sells AB reduce the environmental impacts of the municipal solid waste collection by optimizing the route planning?

**RQ3:** How can Växjö municipality reduce their municipal solid waste collection costs by optimizing the route planning?

**RQ4:** What are the constraints when changing the municipal solid waste collection in Växjö municipality and how can they be overcome?

Figure 20 illustrates a summary framework of the empirical findings covered in this chapter. Overall, the framework shows how the empirical findings are connected to the research question proposed.

![Empirical findings framework](source: Composed by authors.)
5.1 Route Planning In Växjö’s Municipal Solid Waste Collection

5.1.1 Actors In Municipal Solid Waste Collection

In the municipality of Växjö, two actors are responsible for the MSWC as explained by the head of Växjö’s waste department (2014-04-11). The first responsible actor is the waste management department of Växjö municipality, which has 35 employees. The waste management department is controlling and monitoring the collection of 35,000 bins spread over the municipality. Approximately, 1,000,000 bins are collected per year (Växjö kommun, 2014b). The municipality used to have their own RCV’s and employees for the MSWC. In 2011, they decided to outsource the collection to a private company. This outsource decision was made in accordance with an official bid process from the EU legislation and resulted in choosing a private company as waste collection contractor, named Ragn-Sells (Head of Växjö’s waste department, 2014-04-11). This company represents the second actor that is responsible in the municipality of Växjö for MSWC.

Ragn-Sells is a company which offers waste, recycling and decontamination services all over Sweden (Ragn-Sells.se, 2011). The company is part of the Ragn-Sells Group which operates in six countries: Sweden, Denmark, Poland, Spain, Lithuania and Estonia (Ragn-Sells.se, 2014). The company has 1,700 employees in Sweden while the whole group has 2,500 employees in the six different countries (Ragn-Sells.se, 2014). The contract between the municipality and Ragn-Sells is for six years with a possible extension of two more years if both parties agree (General manager of Ragn-Sells Växjö, 2014-04-10). After the contract has run out, the municipality is obligated to start a new bidding process directed to the private companies that handle MSWC in Sweden (Head of Växjö’s waste department, 2014-04-11).

From a total of 550 kg waste, generated per inhabitant and per year (Växjö kommun, 2014b), Ragn-Sells is responsible for the collection of 42% (230 kg) of the total waste. As already explained, the remaining 58% (320 kg) are gathered through recycling centers and recycling stations. The municipality provides bins to the different customers and the waste in the bins are picked up by RCV’s (Head of Växjö’s waste department, 2014-04-11). The MSWC is divided into two types of waste separated in two different bins, which is graphically illustrated in figure 21.
The first type of collected MSW is the mixed waste, which represents 67% (155kg/inhabitant) of the total MSW and is sorted in the grey bins. The mixed waste ends up into an incineration plant to produce heat and electricity. The remaining 33% (75kg/inhabitant) comes from the food waste, which is turned into biogas and is sorted in the green bins (Växjö kommun, 2014a). However, a recent study showed that the municipality of Växjö is the best in Sweden when it comes to the sorting of food waste (Växjö, 2013b).

5.1.2 Municipal Solid Waste Collection

For the MSWC, Ragn-Sells currently use 11 RCV’s and 17 employees as explained by the General Manager of Ragn-Sells Växjö (2014-04-10). The RCV’s can carry around five tons of compressed waste before they have to be emptied, while they usually dispose the waste two to three times per shift (General Manager of Ragn-Sells Växjö, 2014-05-16). Two different kinds of RCV’s are used, those which require that the bin is mounted manually to the RCV and those who can pick up bins from the curbside automatically (Observation RCV Ragn-Sells driver, 2014-04-11). During a normal shift, the RCV’s are operated by two employees while some of them can be operated by just one person (General Manager of Ragn-Sells Växjö, 2014-04-10). The shifts are seven hours long including a 45 minutes break after four hour of working. A bin belonging to
a villa is emptied once every two weeks whereas waste from apartment blocks, commerce and institutions are collected once a week. Since they villas are keeping their bin on their property, they need to roll it out to the curbside on a fixed date (Ibid).

According to the head of Växjö’s waste department (2014-04-11) and the General Manager of Ragn-Sells Växjö (2014-04-10), the MSWC of Växjö is separated in two main geographically separated areas, which are the rural and urban areas as illustrated in figure 22.

Figure 22: Rural and urban areas in Växjö municipality
The rural areas represents the farther surroundings of Växjö city in which it is more difficult to manage the MSWC since the distance between several rural boroughs and houses is high. The geographically spread location between houses triggers a more time consuming collection of bins associated with higher transportation costs (Head of Växjö’s waste department, 2014-04-11). From the total of 35,000 bins in the municipality, 1,600 of them are placed in the rural areas (Head of Växjö’s waste department, 2014-05-08). Ragn-Sells has nine different routes, two of them are in the rural areas and seven of them in the urban. figure 22 illustrates the nine different routes. The bins belonging to those routes are illustrated in different colors although some of the routes are not visual in the image because of the high density in the urban areas (Head of Växjö’s waste department, 2014-04-11).

5.1.3 Route Planning System

The general manager of Ragn-Sells Växjö (2014-04-10) mentioned that the RPS in Växjö municipality integrates a number of technologies. As shown in figure 23, the RPS consists of tracking system technologies (RFID readers, RFID tags, GPS), communication technologies (GPS, GSM, mobile broadband 3G) and an operational software interface with GIS technology (Edpconsult.se, 2014). Moreover, the general manager of Ragn-Sells Växjö (2014-04-10) highlighted that Ragn-Sells owns the office computers and the RFID readers on the RCV´s, whereas the municipality owns all the other technologies. According to the head of Växjö’s waste department (2014-04-11) the RFID technology was tested in Växjö municipality’s own RCV’s a year and a half before Ragn-Sells took over in 2011 (Ibid). The cost of implementing the RFID tags to the 35,000 bins was 1,5 million SEK, which includes costs for a service truck that is driving from bin to bin and installing the RFID tags (Växjö kommun, 2013b).
As figure 22 illustrates, the bins contain RFID tags. All RCV’s, are equipped with RFID readers, onboard computers showing a map, GPS module, GPRS transmitter and electronic collection schedules communicated via 3G. A web-access network application, called EDPMobile, is based at the operational center (General Manager of Ragn-Sells Växjö, 2014-04-10). The application was created by the company EDP Consult AB, and they developed a system for the communication between the RCV’s and the operation center (Edpconsult.se, 2014).

The current framework of the RPS, is illustrated in the following figure 24. The system is based on the interactivity of wireless communication between the bins, the RCV and the operation center software (General Manager of Ragn-Sells Växjö, 2014-04-10; Observation Ragn-Sells RCV driver, 2014-04-11).
These technologies show real-time data during all the operation (General Manager of Ragn-Sells Växjö, 2014-04-10). The RFID reader identifies and registers the RFID tag of the bin after the bin has been emptied. This operation can be seen on the RCV’s onboard monitor as well as from the operation center software as shown in figure 25 (Observation Ragn-Sells RCV driver, 2014-04-11). A screenshot of the planning system shows the bins that are already emptied (colored in green) and the ones that still need to be collected (colored in red), as well as additional relevant information about the customer.

This also enables the route planner to monitor the collection process and identify the location of each RCV (Observation Ragn-Sells RCV driver, 2014-04-11, General Manager of Ragn-Sells Växjö, 2014-04-10). All gathered information is transmitted through GSM and GPRS. The data is integrated in the EDPMobile software, which enables the user to monitor the collection status (General Manager of Ragn-Sells Växjö, 2014-04-10)
As stated by the general manager of Ragn-Sells Växjö (2014-04-10), even with all the available technological equipments, it is still difficult to predict the amount of waste in each bin. Currently, Ragn-Sells estimates that each bin is in average filled up to 75%, based on historical data, and they take into account seasonal changes, like more waste during holidays and less during summer. This information is stored in the RPS to plan the routes and calculate the number of vehicles needed. Although they have tried to make the estimation as accurate as possible, the fluctuations are large. Consequently, it is rather complex to accurately plan the amount of waste each RCV can collect per route (Ibid).

5.2 Environmental Impacts

5.2.1 Emissions Impacts And Goals

The MSWC is one of several business areas for Ragn-Sells. The emission from RCV’s is the second largest emission source for the company and does therefore attract attention for improvements. In 2012, the company was responsible for 0.6 % of the total carbon dioxide emission from heavy vehicles in Sweden (Ragn-Sells, 2012).

As previously mentioned, Ragn-Sells is a member of KNEG, which is a network with members that aim to reduce their transport emissions by 50% until the year 2020.
(Ragn-Sells, 2014). For reaching this goal, Ragn-Sells apply several policies (Ragn-Sells, 2012). They educate their drivers in an environmentally-friendly driving technique called eco-driving. The company is also continuously working towards finding better alternative fuels with less emissions. In addition, they are working towards optimizing the route planning to reduce the total time spent on the road. Ragn-Sells plans to optimize their routes which would lead to 3-6% lower emission rates. In addition to the KNEG goal, Ragn-Sells wants to reduce their carbon dioxide emissions by 50% until 2020 (Ibid).

Växjö municipality developed a waste plan in 1992 where a decision was made to allocate 30 billion SEK in environmental policies (Växjö kommun, 2014a). The head of Växjö’s waste department, (2014-04-11) claimed that there has been an increased environmental focus in the municipality of Växjö since the city was named the greenest in Europe in 2007. For instance, the award led to the acceptance of separating the food waste in a different bin for producing biogas (Ibid).

As already discussed, the municipality of Växjö has both urban and rural areas. Both areas are major sources of emissions in MSWC. However, the rural areas have high emission rates because of the long distance between the bins. The distance is not an issue in the urban areas, although the emission rates are high because of the multiple stops. The stops can be a result of collecting bins but also because of the higher congestion and more complicated traffic areas. Since the engine is continues running when the RCV is standing still, it leads to high rates of emissions (General Manager of Ragn-Sells Växjö, 2014-04-10).

### 5.2.2 Emissions Reducing Equipment

According to the general manager of Ragn-Sells Växjö (2014-04-10) all RCV’s handling the MSWC in Växjö run with RME fuel. The company made the investment to reduce the emission rates of their collection. The main advantage of using RME engines is the decreased carbon dioxide emission rates. The RME engines has 50% less carbon dioxide emission. A disadvantage of RME engines is that they use more fuel than diesel for the same distance. Another disadvantage is that the fuel has to be mixed with diesel when the temperature is below -10 degrees celsius (Ibid).
An additional emission reducing equipment that is owned by the municipality are hubs, which are used in the RCV’s. The hubs have many functions including those regarding environmental impacts. They record the performance and routes of the driver. Since the hubs are tracking the performance of the driver, they can suggest solutions to a more eco-friendly driving with less stops in real-time (Växjö, 2014e).

5.2.3 Other Environmental Impacts

Besides from the emissions, there are other environmental impacts to consider in MSWC. As previously mentioned, the noise coming from the RCV’s has been a problem even though the RCV’s uses more quiet engines. The engines do not completely solve the problem, even though they partly decreased the noise (General manager of Ragn-Sells in Växjö, 2014-04-10).

Additional effects with RCV’s, in general, is the odour from the waste and the congestions caused by multiple stops. These other environmental impacts are larger in the urban areas since the RCV’s spend much more time standing still compared to the driving time spend between collection points in the rural areas (General Manager of Ragn-Sells Växjö, 2014-04-10).

5.3 Cost Effects

5.3.1 Financing Municipal Solid Waste Management
The head of Växjö’s waste department (2014-04-11) stated that the Swedish environmental act stipulates that every household owner must have MSWC and pay a fee. Additionally, the municipalities define the household waste fee besides the municipal waste regulation and a local waste plan (Ibid). By regulation, the MSW fee in the municipality must be non-profitable (Växjö kommun, 2014b). The municipality has
the duty to deliver the same service and same prices for the whole municipality (Ibid). The MSW fee is also environmentally controlled, which means that the municipality chooses the collection and treatment of waste that is best for the environment, for example the separate collection of food waste (Växjö kommun, 2013a).

In Växjö no taxes are used for financing MSWM (Växjö kommun, 2014b). It is fully financed by the waste fee (60 million SEK/year) plus income from recycled materials (3-4 million SEK/year). In particular, the fee finances the following activities: collection and incineration of MSW, food waste treatment, eight recycling-centers for bulky waste, treatment of hazardous and electronic waste and administration and information (Ibid). A more detailed description of which costs the fee covers is explained and graphically illustrated later on in figure 27.

The current waste fee is divided into two parts: First, a basic annual charge per customer and year that finances recycling centers, hazardous waste, and administration (Växjö kommun, 2014b). The basic charge for a villa is 775 SEK, and for a block of flats 480 SEK. Second, a collection charge that finances the collection, incineration and the bin cost. This collection charge varies depending on bin size, number of collection per year, distance to roll bin (less waste equal in lower costs) (Ibid).

According to the head of Växjö’s waste department (2014-04-11), the municipality of Växjö is currently testing a pay-as-you-throw system, before implementing the process in a full scale. He stated, that the throw, or weight-based, collection fee is based on how much waste the customer is producing. The general manager of Ragn-Sells Växjö (2014-04-10) explained how this system works: the waste is measured by weighing the on-site storage bins during the collection service. Therefore, the RCV’s are equipped with a scale to weigh the waste bin, and the customer is identified through an RFID tag on the waste bin. Although, currently only one of the RCV’s are equipped with a scale for testing. Additionally, an RFID antenna and reader on the RCV read the tag on the waste bin when it is placed on the RCV's scale (Ibid). However, the head of Växjö’s waste department (2014-04-11) emphasized, that it might be difficult to charge inhabitants on the waste generated. Moreover, he stated that a pay-as-you-throw system might not work in Växjö municipality since the system will not affect the customers’
mentality and willingness to reduce their waste (Ibid).

5.3.2 Municipal Solid Waste Collection Costs

For the municipality of Växjö, the development of costs for waste from households has increased more than double during the last ten years, from 35 millions SEK in 2000, to 60 millions SEK by 2009 (Växjö kommun, 2014b). Nevertheless, the waste fee and the income from recycled materials cover the costs. This is in line with the regulation that the MSW fee is supposed to be non-profitable as stated earlier.

To be more specific, the costs that arise when managing MSW are separated into four different cost groups (Växjö kommun, 2014b), which are graphically illustrated in the following figure 27 based on the year 2011. The basic waste fee and the income from the recycled materials cover the first group of costs. These costs include costs for customer service and management of invoices, for planning and management MSW, for the treatment of hazardous and electronic waste, for general overhead costs, as well as for Växjö's recycling centers and old waste landfill sites. The second group of costs, which is the most relevant one for this thesis, is fully financed through the second type of waste fee, the collection fee, and contains costs for incineration, bins, and the collection of MSW. For the sake of completeness, costs occur for transporting and treating sludge waste that is covered by a separate fee. Additionally, taxes as well as treatment and capital costs arise for the waste treatment facility in Häringetorp, which are also covered by a separate fee (Ibid). However, these last two cost group are out of scope and will not be further explained.
As mentioned in the background chapter, Ragn-Sells is performing the actual collection of MSW for Växjö. The contract between the Municipality of Växjö and Ragn-Sells covers a period of six years with the possibility to extend the contract for two more years. According to the head of Växjö’s waste department (2014-04-11), the most important subject matter of this contract is the fact, that the municipality is obliged to pay a certain charge to Rang-Sells for every bin collected, which is currently 17 SEK. Additionally, the contract defines, that the municipality is responsible for investments in new technical systems, if these are required, which was for instance the implementation of RFID tags at the bins (Ibid). The purchasing costs for bins is in average 200SEK per bin, no matter which type of bin is ordered. Additionally, the municipality can obtain a quantity discount, as explained by the head of Växjö’s waste department (2014-04-11). In general, the final decision over an investment is in the responsibility of Växjö, as stated by the head of Växjö’s waste department (2014-04-11). One reason for this regulation is the limited contract duration, which might end up in changing contractor. Accordingly, Ragn-Sells has to manage and plan the MSWC with the systems owned by the municipality. Since the municipality outsourced the MSWC in 2011, the number of bins collected per year continuously rose from 650.000 till 1.000.000 (Växjö kommun,
Even though the number of bins has risen considerably, the municipality were able to decrease costs by 10-15% due to the outsourcing strategy (Head of waste management in Växjö, 2014-04-11).

5.4 Constraints Of Changing Municipal Solid Waste Collection

5.4.1 Political Challenges
As mentioned in the background chapter, the politicians willingness to approve and support MSWC changes is a real concern. The local elections for instance those of September 2014 can worsen the political complexion and influence negatively decision-making concerning MSWM (Head of Växjö’s waste department, 2014-04-11). Additionally, the politicians tend to prioritize their reputation by trying to preserve the inhabitants on their side (Ibid). The head of Växjö’s waste department (2014-04-11) expressed that generally politicians believed that creating new projects tend to increase MSWC fees, and thus, the citizens might react negatively which could affect the politicians reputation. On the other hand, the head of Växjö’s waste department (2014-04-11) stated that politicians are misjudging the situation and a rather small rise of the fee may not influence the inhabitants’ mentality and behavior towards generating MSW.

Additionally, the head of Växjö’s waste department (2014-05-08) stated that the municipality possesses two different decision-makers depending on the amount of the MSWM investment. In fact, as shown in figure 28 the technical committee of Växjö municipality is the final decision-maker if the value of the project is under five million SEK (Växjö kommun, 2014c). Unlike, if the estimated budget is over five million SEK, the city council which is the highest governing authority of the municipality, will have the final call to invest in high value projects above five million SEK (Head of Växjö’s waste department, 2014-05-08; Växjö Kommun, 2014d). However, the head of Växjö’s waste department (2014-05-08) expressed that in case of a negative response towards a MSWM investment, the waste department would have to find alternatives.

Currently, Växjö municipality is investigating on the possibility to request supports from other investors such as the European Union to cover projects that the municipality cannot handle due to a lack of resources (Head of Växjö’s waste department, 2014-05-08).
5.4.2 Socio-Demographic Challenges

According to the head of Växjö’s waste department (2014-04-11), the waste generation in Växjö has been affected by social parameters such as family size, education, income per capita and changes in the lifestyle of the inhabitants. He claimed that 80% of the households are currently able to sort their food waste properly. The municipality of Växjö assumes that the customers’ effort of sorting their food waste could achieve 100% by summer 2015 (Växjö kommun, 2014a). As mentioned in the background, the eventual changes in MSWM in Växjö have to be in accordance with the socio-demographic development of the city (Head of Växjö’s waste department, 2014-04-11).

Växjö has experienced constant population growth since 1968, attributed mainly to economic growth and other factors such as age structure, education and health. The population has increased from 56,000 inhabitants in 1968 to nearly 84,000 in 2013. (Smas, et al., 2013) Moreover, the head of Växjö’s waste department(2014-04-11) claimed that the population numbers in the municipality are expected to increase in the coming years. Similarly, according to the head of planning department in Växjö (2014-04-24), the population is predicted to rise by approximately 96,000 inhabitants in the following twenty years as shown on figure 29, which represents an increase of 12% of Växjö inhabitants in 2013.
Figure 29: Forecast of population in Växjö

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Additionally, the head of Växjö’s waste department (2014-04-11) expressed that the current demographic growth is a major challenge and it is planned that it will have a strong impact on Växjö’s MSWM. Similarly, the head of Växjö’s waste department (2014-04-11) and the head of planning department in Växjö (2014-04-24) agreed, that this growth of population might represent a significant issue to the municipality when it comes to the operational improvements of their current MSWC.
5.5 Integration Of Empirical Data

Figure 30: Integration of empirical data

Source: Composed by authors.
6 Bin Sensors In The Market

The purpose of the chapter is to present the sensor solutions in the market. Later, they will be compared to theoretical studies and a RPS will be recommended for Växjö municipality. Afterwards the data from this chapter will be used to calculate possible cost savings. Together with the theoretical framework, this chapter will give ground for a cause-and-effect relationship of implementing such a system for the municipality. Even though market data is not highly reliable, it is interpreted cautiously in the analysis. The reason for the two specific companies used in this chapter is, that Smartbin is the market leader and Enevo is an actor currently working on the local market in Sweden.

6.1 Route Planning Systems For Municipal Solid Waste Collection

6.1.1 SmartBin Solution

SmartBin solutions consist of several technological elements such as sensors, wireless communication systems and different operation central software with several applications. They claim to be the market leaders in their field (SmartBin.com, 2014). SmartBin’s wireless sensors are defined as robust, reliable, durable, easy to deploy and without maintenance requires. Those sensors are remotely configurable and are able to provide information on bin fill levels, geographic position and temperature. Additionally, the sensors are accurate and reliable even under extreme environmental conditions. The GPRS integrated in the system enables to communicate data between the different technologies. Similarly, the GPRS wireless network has a wide coverage and allows real-time transmission of information (SmartBin.com, 2014).

As shown on figure 25, SmartBin solution framework involves the use of sensors, cellular networks, web and mobile technologies. The framework operates as follow: the sensors estimate when the bin has reached its full capacity, later the sensors communicate through the GSM/GPRS network to the server (SmartBin.com, 2014).
6.1.2 Enevo Solution

Enevo’s solution framework estimates the fill level of bins. Enevo provides this solution in order to optimize route planning (Enevo, 2014c). Additionally, Enevo’s sensors are bin fill level monitoring devices which can optimize the route planning. Enevo’s sensors can be installed in all kind of bins. The sensors are installed and mounted under the bins’ lid. Furthermore, the sensors can transmit data and are built and designed to accurately measure fill levels in harsh environmental conditions. Similarly, the sensor can automatically detect events such as container collection, vandalism and fire. (Enevo, 2014a)
The framework illustrated in figure 27 is based on several activities: fill level measurement, analysis and modelling of the data coming from the sensors, and forwarded to route planning. To be more specific, the sensors monitor the bins fill rate in real-time. The bin level measurements are performed at configurable set of times, usually once per hour. Furthermore, via GSM and 2G/3G wireless communication, the information regarding the bin fill levels are sent to ENEVO’s server for analysis and display to the customer in the Enevo One Collect platform. The last step refers to the route operation. Indeed, the list of bins that still need to be collected is sent to the drivers through the onboard management system. Enevo enables the customers to have an easy and wide access to integrate One Collection platform to any onboard terminal management system (Enevo, 2014a).

In the telephone interview with the Key Account Manager of Enevo (2014-05-12), the process of implementing their system within a municipality was described. This starts with implementing a couple of sensors at a number of bins to run tests and identify the possible benefits and constraints of the sensor system. In addition, the results and the performance could be benchmarked and analyzed to check the feasibility of such sensors. Detailed information about the type of bins, the type of waste and the process of collecting MSW is required.
6.2 Enviormental And Cost Effects

According to both mentioned companies, applying their systems will decrease the environmental effects since less distance needs to be covered and less time is spent on the road, leading in a reduction of emissions (Enevo 2014c; SmartBin.com, 2014).

SmartBin.com (2014) claimed that their system increases efficiency in the waste collection by providing remote real-time monitoring of bin fill-level, and hence, enables an optimized route planning system to collect bins just if they are filled. Moreover, their system can reduce collection costs by over 30% (Ibid). In fact, the company just recently published the successful implementation of their SmartBin solution by the leading Spanish waste collection service provider Epremasa, which installed SmartBin’s monitoring solution in 74 municipalities in the province of Cordoba to achieve cost savings (SmartBin News, 2014-03-10).

Concerning Enevo, the company strives to become the foremost global supplier of logistical solutions for the waste management and recycling industry (Enevo, 2014d). As stated by the Key Account Manager of Enevo (2014-05-12), the company just recently entered the market and tries to keep costs about their sensors confidential. However, their system is calculating the best possible routes and schedules for vehicles based on real-time monitoring sensors of each bin, which typically results in savings between 20-40% of the waste collection costs (Enevo, 2014b). In November 2013, Enevo announced the successful implementation of their system within several Finish municipal waste management companies (Enevo.com, 2013). They are currently also testing their sensors in a municipality in Sweden (Key Account Manager of Enevo, 2014-05-12). The first company of those that used the system on a large scale (for around 90,000 residents) has been able to minimize collection costs by almost 40% after installing the system in 2012 (Enevo, 2014b).
7 Analysis

The analysis chapter contains data gathered from the theoretical, empirical and market solution chapters regarding route planning in MSWC in order to suggest an RPS for Växjö municipality. Additionally, the environmental impacts, cost effects and possible constraints of implementing such a system will be analyzed. In addition, the authors will critically reflect over the results drawn from previous research. The structure of this chapter has been based on the four research questions stated below:

**RQ1:** How can the municipal solid waste collection in Växjö municipality be improved through an optimized route planning?

**RQ2:** How can Växjö municipality and Ragn-Sells AB reduce the environmental impacts of the municipal solid waste collection by optimizing the route planning?

**RQ3:** How can Växjö municipality reduce their municipal solid waste collection costs by optimizing the route planning?

**RQ4:** What are the constraints when changing the municipal solid waste collection in Växjö municipality and how can they be overcome?

Figure 33 illustrates a summary framework of the analysis covered in this chapter. Overall, it shows the relation between the different sub chapters and refereed how these concepts are related to the research questions of this paper.

Source: Composed by Authors.
7.1 Route Planning In Växjö’s Municipal Solid Waste Collection

7.1.1 Route Planning Problems

Despite the fact that several steps have been taken to improve the MSWM in the municipality of Växjö (Head of Växjö’s waste department, 2014-04-11), there is still need to optimize the route planning of the current MSWC. The main problem in the MSWC emerged from the fact that the municipality is not using a RPS that is able to accurately calculate the fill level of the bins. The actors involved (Växjö municipality and Ragn-Sells) are collecting the MSW with a static solution, where the quantity and volume of the waste inside the bin is estimated through historical data (General manager of Ragn-Sells Växjö (2014-04-10)). For each route the bins are in average filled up to 75% of their capacity, which is determined based on historical data. Additionally, they take seasonal changes (e.g. more waste during holidays and less during summer) into consideration (Ibid). Nevertheless, the MSWC should instead be treated according to a stochastic nature (random waste in every bin of the municipality) where the quantity of the waste inside the bin is estimated through real-time technologies, as shown by Faccio, et al. (2011).

Following this idea, it is possible to categorize the MSWC in Växjö as a SVRP, in which the content of the bin is variable. Consequently, it is impossible to estimate an accurate amount of waste in the bins without monitoring the bin fill level in real-time. As the general manager of Ragn-Sells Växjö (2014-04-10) expressed, the fluctuations of waste in the bins are significant and hence it is complicated for Ragn-Sells to plan an ideal route. In addition, collecting bins with a low fill rate leads to unnecessary stops. This lack of bin level estimation creates a higher fuel consumption per tons of waste collected, as demonstrated by Faccio, et al. (2011). As a result, the SVRP in Växjö’s MSWC, triggers another routing problem, which is the CVRP explained by Kim, et al. (2006) and McLeod and Cherrett (2008). This CVRP problem relies on the volume and weight capacity that an RCV can handle (Kim, et al., 2006; Faccio, et al., 2011). The lack of information regarding the weight of the bin content results in inaccurate estimations at the operation center system of Ragn-Sells, to plan the exact amount of waste and number of bins each RCV can collect.
Lastly, there is no predefined route for the RCV drivers to follow in the current route planning of Ragn-Sells. Each driver is assigned with certain areas and they can individually choose in what order they collect the bins (General manager of Ragn-Sells Växjö, 2014-04-10). Therefore the route planning is static. As Menikpura, et al. (2013) claimed, a static solution is no longer sufficient. In that case, there is a need for technological solutions to Växjö’s MSWC to solve the aforementioned problems.

7.1.2 Suggested Route Planning System

7.1.2.1 Route Planning System With Sensors

The suggested RPS with sensors is build up based on the established real-time technologies that the municipality is currently using. In addition to the existing system, sensors that have been studied by Vicentini et al. (2009), Rovetta, et al. (2009) and Faccio et al. (2011), are suggested for the purpose to solve the route planning problems explained in the previous section.

Figure 34 illustrates the suggested RPS, which follows a similar framework as currently used in Växjö’s MSWC. The technologies related to the identification of the bin, to the wireless communications, and to the collection status of the route as well as to the RCV position would be kept in the suggested RPS. The main difference in this suggested RPS are the sensors that are mounted under the lid of each bin in order to monitor the waste content Possible sensors are discussed and analyzed by Vicentini, et al. (2009), Rovetta, et al. (2009) and Faccio, et al. (2011), and market solutions have been presented in chapter 5 from several suppliers. However, differently to the current system, the sensor technology is now the core and fundamental element of the suggested RPS.
In addition, the flow of information in this system will change as illustrated in figure 35. First the RFID tag identifies the bin information (Arebey, et al. 2010, 2012; Hannan, et al., 2011, 2012; Hannan, et al., 2013) and the sensor equipment manages the measurement of the waste content inside the bin (Rovetta, et al., 2009; Vicentini, et al., 2009; Faccio, et al., 2011). The two sensor suppliers Enevo (2014a) and SmartBin (2014), explained their sensor technology in a similar way, that the sensors are constantly measuring the fill level of the bin and transmitting the gathered information in real-time to the operation center software. When the information is received and analyzed, depending on the estimations of the waste replenishment level in real-time, the operation center software optimizes the planning and suggests the most efficient route (Faccio, et al., 2011).
Differently from the current RPS, the operation center did not have real-time information about the bin fill level, instead the only information transmitted after the RCV approached to the bin area, was the collection status (General manager of Ragn-Sells Växjö, 2014-04-10; Växjö kommun, 2014b). This new flow of information aggregates more data about the collection process, adding accurate volume estimations inside the bin, shown by Johansson (2006). Accordingly, the operation center software can predefine a precise scheduling and routing plan for the RCV through the GIS software.

It is important to highlight that the suggested RPS is the one using sensors to estimate the bin fill level. The other systems, including cameras in the RCV and in the bin, as well as the multiple set of sensors has not been suggested for the municipality of Växjö, based on the following reasons:
Firstly, the usage of RPS with RCV cameras implicates a time consuming and inefficient manual adjustment of the camera by the driver, for taking a proper image of the bin, as explained by Hannan, et al. (2013). This drawback towards the low automatization level is the reason why the cameras mounted at the RCV have not been suggested for the MSWC in Växjö municipality. Nevertheless, the automatization of the collection process was taken in consideration in the suggested RPS, in which the manual operations of the personnel involved in the MSWC are minimized. In addition, the RCV cameras cannot provide with real-time information about the bin fill level (Rovetta, et al., 2009) since the RCV must be present when capturing the image.

Secondly, the RPS approach with cameras in the bin for image processing combined with the multiple set of sensors is not suggested for Växjö municipality. Although, this approach can estimate the amount of waste in the bin, as demonstrated by Rovetta, et al. (2009) and Vicentini, et al. (2009), the system has an inaccurate estimation since the camera image process have issues towards the position of the camera (Islam, et al., 2014). Another drawback with the system is the number of different technological devices needed in the bin, which would require a major investment. For these reasons, neither the camera at the RCV nor the camera in the bin with a multiple set of sensors were suggested for Växjö’s new RPS.

7.1.2.2 Route And Collection
As previously mentioned, there is a difference between static and dynamic routes. Indeed, the static routes are predefined (Ghiani, et al., 2003) whereas the dynamic routes are based upon real-time information (Giaglis, et al., 2004; Berbeglia, et al., 2010). In total, Ragn-Sells has nine routes for Växjö municipality, although the routes are not specifically planned since only the areas are decided and not the order of the collection (General manager of Ragn-Sells Växjö, 2014-05-16). The MSWC in Växjö is thus static, which would change by using the suggested RPS with sensors having no predefined static routes. The routes would be created by the suggested RPS before the shift starts, based on the bins that have reached the replenishment level. Thereby, this approach would be dynamic.
As described by Faccio, et al. (2011), the municipality has to decide on an optimal replenishment level when implementing real-time technologies in the RPS. Currently, the municipality is using an average of 75% fill rate in the bins when planning the route, even though the individual content of the bins vary to a great extent (General manager of Ragn-Sells Växjö, 2014-04-10). Therefore, a reasonable replenishment level used in a RPS with sensors would be to slightly rise the figure to 80%, this way they can exclude the bins which are below the replenishment level. By having a figure below 100%, a safety time is added for the bin to be collected before it is full. Furthermore, the authors of this thesis suggest a different method for the collection in rural area than for the collection in the urban area. Since the distances in the rural area is large, a similar method which was discussed by Johansson (2009) would be useful. In the rural area, the operation center software should plan all the bins which have reached the replenishment level of 80% in addition to all the nearby bins which have reached 70%. Thereby, they can reduce the total distance covered by not having to visit the same area too often.

7.1.2.3 Route Planning Problems With The Suggested System

Ragn-Sells does not have any exact predefined route and additionally two VRP’s were identified with their current MSWC, which are the SVRP and the CVRP. The effects of the suggested RPS with sensors are supposed to minimize those issues, which is explained in the following.

Regarding the SVRP, the municipality is currently having issues with estimating the amount of waste in the bins, as stated by the General manager of Ragn-Sells Växjö (2014-04-10). The main advantage of implementing the sensors is the ability to gather real-time data about the amount of waste in each individual bin (Patricia, et al., 2010). As explained, the software will define a route for each driver before the shift starts based on the fill rate of the bins. According to Johansson (2006) and Faccio, et al. (2011) the driving distance can be reduced using a RPS with sensors, therefore the assumption could be made that Växjö could reduce the total distance covered during the MSWC. Nevertheless, Bing, et al. (2014) claimed that the distance is not of major importance since the issue with MSWC is the numerous stops made when collecting the bins. The current lack of information leads to unnecessary stops and driving distances. As described by Faccio, et al. (2011) a RPS with sensors can reduce the number of stops
made and the number of operating RCV’s since they only empty full bins. Another aspect to consider is the reduced time, showed in the study of Zsigraiova, et al. (2013), that optimizing routes lead to a larger reduction in time spent than distance driven on the road by the RCV’s. By reducing the distance covered and time spent on the road in addition to a reduction in number of stops made, the SVRP can be managed by implementing a RPS with sensors.

The CVRP is closely connected to the SPVP and is a current issue with Växjö’s MSWC. They know that the RCV can carry five tons of waste (General manager of Ragn-Sells Växjö, 2014-05-16) and that the bins have in average a three quarters fill rate, although that estimation fluctuates especially for each individual bin (General manager of Ragn-Sells Växjö, 2014-04-10). By implementing a RPS with sensors, they can estimate more accurately how many bins can fit in the RCV. As mentioned above, the Växjö municipality would only collect the bins that reached the defined replenishment level and can therefore predict how many bins they can empty before emptying the RCV. This will allow the software to utilize the number of RCV’s and plan the disposal trips from the collection area in the most efficient manner, as described by Faccio, et al. (2011). It would, though, still be difficult to exactly predict how many bins the RCV can collect since the sensors measure the volume of waste in the bins rather than the weight. Since the RCV compresses the waste, the volume does not say exactly how much space it would take in the RCV although it would help the MSWC in Växjö to be more accurate than they currently are.

Even though two VRP’s are minimized with the RPS with sensors another one is created that has so far not been an issue for Växjö municipality, which is the VRPTW explained by Faccio, et al. (2011). The villas in the municipality have to roll out their bins to the curbside before they can be collected. Currently, the collection is handled by having a set date once every second week for Ragn-Sells to collect the full bins (General Manager of Ragn-Sells Växjö, 2014-04-10). Using the RPS with sensors, bins would be emptied when the replenishment level is reached. However, the people living in the villas would not know when to roll out the bins from their property to the curbside. This issue is not discussed by any previous study, therefore it is difficult to suggest a system to solve this problem. There are two possible solutions although none of them have been tested or suggested by any previous researcher. One solution would
be to mark the bins and tell the households to roll out the bin once the waste reaches that mark. An issue with that solution would be, that the bin could stand on the curbside for a few days before collected since the bin might not be collected the same day as it reaches the replenishment level. Another solution would be to add an application to the software used to plan the routes, which sends a message to the households living in the villas on the day of the collection. The issue with that solution would be, if nobody in the household had the opportunity to roll out the bin on that specific day, the bin would stay uncollected and would have to be collected on another day.

However, figure 36 shows how the suggested RPS with sensors would affect the MSWC in the municipality of Växjö. The following figure shows the real-time technologies and how real-time information flow effects the route planning and thereby the actual collection. The effects of the system have a number of benefits, which were just described and are presented in the figure.

Figure 36: MSWC in Växjö with the suggested RPS with sensors

Source: Composed by authors.
7.2 Environmental Impacts

7.2.1 Environmental Impacts in Växjö Municipality and Possible Improvements

As previously mentioned, large investments have been made to collect real-time data from the MSWC in Växjö. These investments were mainly implemented to control the contractor Ragn-Sells and their performance (Head of Växjö’s waste department, 2014-04-11). As a result, the technologies do not have a major part of the route planning for Ragn-Sells. If improvements were to be made in the route planning, the environmental impacts of the MSWC could be reduced.

The municipality of Växjö is divided into two areas: urban and rural. According to the study from Larsen, et al. (2009), the major emissions from MSWC are coming from collections in the rural area. The same conclusion was drawn by Sonesson (2000). As mentioned by the head of Växjö’s waste department (2014-04-11), the major improvement area is the rural part. The RCV’s have to drive long distances to collect small amounts of waste compared to the urban area where the density is high (Ibid). There are other environmental impacts to consider as shown by Aranda Usón et al. (2013), who claimed that as a result from MSWC, noise as well as congestion and odour are important aspects to consider when discussing environmental impacts. Those issues are larger in the urban areas, stated by Faccio, et al. (2011). Similarly, the general manager of Ragn-Sells Växjö (2014-04-10) expressed that odour, noise and congestions are other environmental impact of the MSWC and the problems are mainly in the urban areas.

Additionally, Ragn-Sells has set up high goals for exhaust emission reductions since they want to decrease emissions by 50% until 2020 compared to the emissions emitted in 2005 (Ragn-Sells, 2014). The company also set up a goal for reducing carbon dioxide emissions by 50% until 2020 compared to 2008 (Ibid). Since Ragn-Sells did not operate in Växjö municipality before 2011, there are no figures to compare the aforementioned goals, although it is clear that the company is constantly working towards reducing emissions.

One major investment made by Ragn-Sells is the use of RME engines, described by the
General Manager of Ragn-Sells Växjö (2014-04-10), which emit 50% less carbon dioxide and have a smaller rate of reduction for other gases (Jalava, et al., 2012). Since the fuel needs to be mixed with diesel when the temperature might get below -10 degrees celsius (Stockholms Stad, 2008) the total reduction in transport emissions are not as high as they are when comparing RME to diesel. In addition, growing population (Head of planning department in Växjö Kommun, 2014-04-24) will require more time on the road, which will make the transport emission reduction difficult to achieve. For instance, the head of Växjö’s waste department (2014-04-11) claimed that the number of bins emptied increased from 650,000 to 1,000,000 since Ragn-Sells took over the MSWC in Växjö. Although Ragn-Sells are continuously working towards less environmental impact, the municipality is the party which makes all the technical investments. Since Växjö was named the greenest city in Europe, there has been an increased attention from politicians to invest in the waste department (head of Växjö’s waste department, 2014-04-11), which enhances the possibility to invest in environmental improvements.

7.2.2 Quantifying And Reducing The Environmental Impact

As previously shown in table 7, theoretical studies demonstrated that emission rates can be reduced when a RPS with sensors in MSWC is used, although they all struggle to account for the exact impacts of such a system (Johansson, 2006; Faccio, et al., 2011). One possible reason is, that the market is more focused on reducing costs, while environmental impacts are of secondary importance, stated by Bing, et al. (2014). As a result of the lack of empirical and theoretical data it is impossible to estimate any specific emission reductions for Växjö’s MSWC. As Punkkinen (2012) mentions, the other environmental impacts are not quantifiable and it is therefore difficult to measure them, the same applies for Växjö’s MSWC.

Although the previous studies do not quantify their results, it is clear that the route is optimized by the implementation of a RPS with sensors and therefore the environmental impacts are improved. The same assumptions can be made for Växjö municipality if they implement such a system. As previously mentioned, both the municipality and the contractor want to reduce their emission (Head of Växjö’s waste department, 2014-04-11; General manager of Ragn-Sells Växjö, 2014-04-10). In addition, the congestion and noise are other environmental impacts that, according to the previous studies, could be
improved by a bin level sensor system. The improvements would be a result of a reduction of RCV’s used, as well as less time used and less distance covered on the road.

Ragn-Sells in Växjö collect data regarding the fuel consumption and emissions which means that an emission reduction would be possible to calculate if a RPS with sensors is implemented, although no specific quantitative data is shared for this thesis. There are different ways to quantify the environmental impact of MSWC. The calculation can be emission specific where carbon dioxide is the most used. It could also be focused on the fuel consumption, similar calculations from Larsen, et al. (2009) and Sonesson, et al. (2009). Since Ragn-Sells already made the investment to have modern RCV’s with less emission, the next step to consider is to reduce the fuel consumption. Naturally, the emission rates would be reduced at the same pace as the fuel consumption. The data about emission from the RCV manufacturer could easily be applied in any emission reduction calculations.

To measure the environmental impacts, Zsigraiova, et al. (2013) calculated the fuel consumption rates based on time spent and distance covered on the road by the RCV’s. Although, the difference between the time and distance shows the weakness in both measurements. The distance does not take the stops into account and the time does not consider the distance nor the speed between stops. A more relevant figure would be to calculate the total emissions per tonne of waste collected, similar to Larsen, et al. (2009) and Sonesson, et al (2000). The formula suggested follows the same logic as in figure 37 in the theory chapter, although it is adopted to RME rather than diesel. \( R_{\text{total}} \) is the total RME consumption. \( R_{\text{t,empty}} \) is the RME consumption when the RCV drives empty from the garage to the collection area and from the treatment facility to the next collection area or to the garage. \( R_{\text{t, full}} \) is the RME consumption when the RCV is full and is driving from the collection area to the treatment facility. \( M \) is the tons of MSW collected.
The reason for suggesting such a model with fuel consumption per liter of tons in the collection is that the city is growing fast, as explained by the head of planning department in Växjö Kommun (2014-04-24). In addition, the consumption is growing as the total number of bins grew from 650,000 to 1,000,000 since Ragn-Sells took over the MSWC in 2011. Therefore, the total fuel consumption would be an irrelevant figure to compare between different years and before and after a RPS with sensors would be implemented. The fuel consumption and the emissions could simply grow because of an increase in waste and population. Therefore the fuel consumption per tonne collected is more relevant and is easier to benchmark.

The head of Växjö’s waste department (2014-04-11) mentioned that the rural area is a higher source of emissions than the urban area as a result of the long distances. As mentioned, there is a lack of quantitative data to make certain conclusions. However, a fair assumption could be made on the basis of the study of Larsen et al. (2009) about fuel consumption for different parts of municipalities, which is relevant for Växjö. In this study, the collection in the rural area required 2-3 times more fuel than in the urban area (Ibid). Similarly, Sonesson (2000) showed that the rural area produced less than half the amount of waste compared to the city, although the collection required 40% more fuel. A conclusion to be drawn for Växjö, is that the 1,600 bins in the rural area are of big environmental importance even if they represent such a small part of the total 35,000 bins. Therefore the major improvement area per tonne of waste is in the rural area although the number of bins are considerably more in the urban area, meaning that a smaller improvement in the urban area can result in a greater effect on the environmental impact. The issues in the rural area is the total distance required to collect the waste and in the urban area, the total time spent because of the numerous stops. Based on the aforementioned formula, a separation between rural and urban areas is suggested which is illustrated in the following table. Currently, the table does not

\[ R_{\text{collection}} = \frac{R_{\text{total}} - (R_{\text{t, empty}} + R_{\text{t, full}})}{M} \]

Source: Composed by authors based on Larsen, et al. (2009).
contain any data about the fuel consumption. Although it could be used by Ragn-Sells and the municipality to understand and highlight the difference between the geographical areas and to be able to compare the performance of an implemented RPS with sensors.

Table 9: Fuel consumption in different areas of Växjö

<table>
<thead>
<tr>
<th>Area</th>
<th>$R_{\text{collection}}$</th>
<th>$R_{t,\text{empty}}$</th>
<th>$R_{t,\text{full}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Area</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rural Area</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Composed by authors.

7.3 Cost Effects

7.3.1 Cost Effects For Växjö When Using Route Planning System With Sensors

If the municipality decides to invest in the explained RPS with sensors, several costs would arise as explained by Faccio, et al. (2011). One of the main decision-making aspect whether or not the required expenditures for the suggested RPS will be undertaken, is the cost aspect of the new system. Therefore, the possible cost savings have to be identified and highlighted. Several authors such as Rovetta, et al. (2009), Arebey, et al. (2012), and Hannan, et al. (2012) demonstrated in their scientific research that the implementation technologies, which identify the quantity of waste in the bins could reduce costs for MSWC. However, none of these studies presented total figures of the potential cost savings. How much could be saved depends on several parameters, which end in multiple scenarios with different cost effects, as described by Faccio, et al. (2011). This complexity might be one reason for the lacking information about scientific results regarding costs. The study of Johansson (2006), which analyzed the effects of the waste level sensors installed at recycling containers, showed that it is possible to reduce collection costs by 10% to 20%. Since the recycling containers of the municipality Växjö are collected by the producers itself, it is the responsibility of the producers to investigate whether or not they should consider investing in such technological systems. Nevertheless, Johansson (2006) described the same RPS as is
suggested for the municipality of Växjö. Besides this, investment costs in these sensors have not been considered (Johansson, 2006), which is the reason why the results cannot be fully reflected onto the MSWC in Växjö.

Nevertheless, some estimations about cost savings were given by the two sensor suppliers Enevo and SmartBin. They claimed that the implementation of the bin monitoring sensors can result in significant savings of MSWC costs. To be more precise, SmartBin (2014) stated that their sensor systems could reduce the collection costs by more than 30%, while Enevo (2014b) presented savings between 20-40% of the waste collection costs. Both companies published successful implementations of their systems within different municipalities. Another example is given by the previously mentioned RecycleSmart Solutions Inc. from Canada. They have been testing their sensor technology already for two years and demonstrated that installing the sensors can cut waste and recycling costs by an average of 25%, as declared by Mr. Bell in an interview with Theglobeandmail.com (2013-06-26). Those aforementioned suppliers of sensor solutions published all their numbers, which is why these figures ought to be interpreted cautiously since they might not be entirely reliable.

To calculate the possible cost savings of the RPS with sensors, when implementing at the municipality of Växjö, certain assumptions have to be made. Due to the lacking scientific information about cost effects of the proposed sensor system, the given cost saving percentages of the suppliers were used. Additionally, the costs to collect one waste bin within the municipality of Växjö and the number of collected bins per year were stated by the head of Växjö’s waste department (2014-04-11). The possible annual cost savings with the waste level sensor technology can be roughly estimated. The calculations are separated based on the worst (20% savings) and best case scenario (40% savings) addressed by Enevo and SmartBin as illustrated in the following table.
Table 10: Possible annual cost savings for the municipality of Växjö

<table>
<thead>
<tr>
<th>Possible savings using RPS with sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection costs per bin (SEK)</td>
</tr>
<tr>
<td># bins collected per year</td>
</tr>
<tr>
<td>Collection costs per year (SEK)</td>
</tr>
<tr>
<td>Annual savings (%)</td>
</tr>
<tr>
<td>Annual savings (SEK)</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Source: Composed by authors based on Växjö kommun (2014b); Smartbin (2014); Enevo (2014b) and Theglobeandmail.com (2013-06-26).

When implementing the RPS with sensors and optimizing the route planning, the municipality of Växjö could achieve yearly cost savings ranging between 3.4 million SEK to 6.8 million SEK. Several possibilities to save costs were explained by Faccio, et al. (2011): For instance the reduction of the operational costs for fuel consumption, as well as for the maintenance of the RCV, which both depend on the covered distance. One of the major benefits of the sensors is the real-time data about the waste bin-level, which allows the operation centre software to plan the routes precisely and in advance. In addition, fewer kilometers have to be driven by the RCV's, which results in less fuel and maintenance costs. Because of the low average speed and frequent stops for unloading the bins’ content, RCV's have significant operation costs (Johansson, 2006), especially in the urban area. The RPS with sensors would minimize the emptying operations, due to the fact that only the bins reaching the replenishment level will be collected, which will in turn result in less operational costs. The additional costs that arise, as explained by Johansson (2006), such as labor costs for the crew, which depend on the number of vehicles employed could also be reduced due to less, but fully utilized, RCV's that are required with the new route planning approach. The fact that the new RPS with sensors could reduce the number of employed RCV's is shown by Faccio, et al. (2011). However, the previously explained environmental impacts are not considered in this calculation, which increases the feasibility of the proposed sensor technology. Besides possible cost savings that might occur with the new sensor system, several
investment costs have to be undertaken which will be explained in the following chapter.

### 7.3.2 Equipment And Installation Costs For Växjö

The suggested RPS with sensors would require investments in new technological equipment, as shown by Faccio, et al. (2011). Costs for installing the equipment at the bins, RCV's and the operation centre will be necessary (Ibid). Adopting the new equipment to the already existing collection equipment would arise additional costs. However, as in the previous chapter, one of the main drawbacks when calculating the equipment and installation costs is the lacking scientific information about relevant costs. As stated by Rovetta, et al. (2009), costs for sensors have not yet been fully estimated because of the limited number of prototypes manufactured. Even though, this statement is from 2009, the limited availability of needed cost figures is still the case. One of the main reasons for this is, that relevant suppliers of these waste level sensors more or less just entered the market and try to keep cost information confidential, stated by the Key Account Manager of Enevo, Petteri Maukola (2014-05-12). Accordingly, Rovetta, et al. (2009) used in their study an estimation of costs for sensors ranging between 20-30% of the bin purchase price. The municipality of Växjö purchased waste bins for approximately 200 SEK per bin, due to a quantity discount. When applying the 20-30% estimation of Rovetta, et al. (2009) to the purchase price of Växjö, one waste level sensor would cost between 40-60 SEK, which is not very realistic in comparison to prices gathered from the market. Again, an example of costs for sensors to measure the content level of a waste bin are given by Colin Bell, managing partner and co-founder from RecycleSmart Solutions Inc. He stated in the recent interview with "The Globe and Mail.com" that one sensor costs between 1.525 to 1.830 SEK (Theglobeandmail.com, 2013; Xe.com, 2014)

When calculating the equipment and installation costs of the waste level sensor technology for the municipality of Växjö, certain assumptions have to be made. Even though the municipality pays the same fee per collection to the transport company Ragn-Sells, no matter if the bin has been collected within the urban or the rural area, the calculation is divided into both areas. One reason is the fact that the expected cost effects from the RPS with sensors will be greater in the rural area, due to the longer
Another reason is the possibility to demonstrate how big the expenditures would be if the sensor technology were just implemented within one collection area. Accordingly, 33,400 bins are to be collected in the urban area and 1,600 bins in the rural collection area. Due to the most recent information, and again, due to the lack of reliable scientific cost information, the just mentioned purchase costs of 1.525-1.830 SEK per sensor are used to calculate the equipment costs, even though these numbers seem relatively high. Another assumption is made, regarding the installation costs of sensors. Additional costs arise, when implementing the sensors at the bins, since a service truck has to drive from bin to bin (Växjö kommun, 2013b). Hence, labor costs, as well as fuel and maintenance costs arise, when implementing the sensors at all 35,000 bins. Installing the RFID tag at the 35,000 bins within the municipality summed up to 1,5 million SEK (Växjö kommun, 2013b). By assuming more or less the same amount of work for installing the waste level sensors at the bins, installation costs per bin are estimated with 42 SEK. By multiplying the quantity of bins for each collection area with the equipment costs per bin plus the installation costs, the total equipment and installation costs range in between 54,9 million SEK and 65,6 million SEK. The calculation of the equipment and installation costs can be seen in the following table.

<table>
<thead>
<tr>
<th>Equipment and Installation costs</th>
<th>Collection Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td># of bins</td>
<td>33,400</td>
</tr>
<tr>
<td>Equipment costs per bin (SEK)</td>
<td>1,525</td>
</tr>
<tr>
<td>Installation costs per bin (SEK)</td>
<td>42</td>
</tr>
<tr>
<td>Equipment costs (SEK)</td>
<td>50,935,000</td>
</tr>
<tr>
<td>Installation costs (SEK)</td>
<td>1,402,800</td>
</tr>
<tr>
<td>Total costs per collection area (SEK)</td>
<td>52,337,800</td>
</tr>
<tr>
<td>Total costs (SEK)</td>
<td>54,845,000 - 65,520,000</td>
</tr>
</tbody>
</table>

Source: Composed by authors based on Växjö kommun (2014b) and Theglobeandmail.com (2013-06-26).

However, as explained in the empirical chapter the head of Växjö’s waste department, (2014-04-11), most of the required technologies (such as RFID, GPRS, GIS) are already implemented at the different levels, which results in major savings and minimizes the necessary investment costs, which would be higher than calculated if they would not
have made major investments already. In fact, no investment costs are required at the vehicle level. For the bins, the required RFID tags are already implemented, which is why the sensors would be the only technology that needs to be purchased and installed. At the operation centre, one possibility is to link the existing RPS with the available features of the new real-time data of the bin sensors. Another possibility is to purchase a new RPS, which could in our case replace the existing planning system. However, the latter one would require higher investment expenditures, which is why it is more feasible if the new sensor system will be adopted and linked to the existing RPS, which results in less investment costs.

In general, as highlighted by Faccio, et al. (2011) and Di Maria and Micale (2013), MSWC is expensive to operate in terms of investment costs (costs for bins, vehicles and the operation centre) and operational costs (for fuel, and maintenances). For a more detailed investment calculation, the necessary costs have to be identified accurately in combination with requesting a customized quotation from waste level sensor suppliers, to compare and analyze these offers. This would provide financial clarity for judging the feasibility of this sensor technology investment and might be a next step for the municipality of Växjö.

### 7.3.3 Economic Feasibility

The MSWC of Växjö is fully financed by the waste fee, in particular by the collection charge, and income from recycled materials as explained in the empirical chapter (Växjö kommun, 2014b). Additionally, no taxes are used for financing MSWM (Ibid). However, the costs for the investment in the RPS with sensors will not be covered by the waste fee, nor by income from recycling centrals. In fact, the investment have to be made by either the city council or the European Union, as stated by the head of Växjö’s waste department (2014-05-08). This also means that the waste fee will not be increased.

When implementing the sensor technology, several possibilities for saving MSWC costs arise as shown by Faccio, et al. (2011). These cost savings are necessary to cover the required investment expenditures, explained in the previous chapter. Consequently, the feasibility of implementing the suggested sensor technology at the municipality of Växjö would increase. As explained by Ghose, et al. (2006) and Tavares, et al. (2009),
the collection of MSW represent an essential public service. According to these authors, investments in the MSWC service do not necessarily require a justification in form of return on investment or profit margins. However, as shown by Tavares, et al. (2009) and Aranda Usón, et al. (2013), managing MSW is very cost-intensive, which is why investments in MSWC have to be justified in form of environmental, technological and economic feasibility. One possibility to address the economic feasibility was given by Faccio, et al. (2011), who applied traditional indicators for economic feasibility studies such as the Payback Period. The payback period highlights the duration of the period to refinance the initial investment (Ibid).

Calculating the payback period for the investment of the sensor technology in the bins of the municipality of Växjö, which is graphically illustrated in the subsequently figure, should be based on the following reasonable assumptions. As already calculated in the previous chapters, the municipality of Växjö would have to pay minimum 54.9 million SEK for the investment when implementing the waste level sensors for all collection areas. For the reason that Växjö municipality would buy a large quantity of sensor, the lower investment cost is used in the calculation. The following figure highlights the payback period of the investment in the RPS with sensors. The investment costs are shown with the blue line in the figure. The other lines represent the cumulative savings the municipality could achieve every year, which is in the best case 40% (red line), in the worst case 20% (green line), and in average 30% (purple line), as shown by SmartBin (2014) and Enevo (2014b). Consequently, the payback period according to the above mentioned parameters ranges between 8 and 16 years.
In comparison to the findings from Faccio, et al. (2011), the calculated payback times are relatively high. One of the reasons might be the high investment cost, which was set because of the limited available information. The assumption can be made that the investment cost calculated in this payback time model are not realistic since the municipality could expect a major size discount on the sensors. Since the study of Faccio, et al. (2011) has similar conditions with those in Växjö, such as the number of inhabitants (100,000) or the biweekly collection of bins, the results could be reflected onto Växjö. In their study, the payback period is almost always less than three years, while only in one case where certain parameters were extreme, the initial investment in real-time technologies is not recovered within the first five years (Faccio, et al., 2011).

Even though the payback period is calculated, the waste department has to be non-profitable (Head of Växjö’s waste department, 2014-04-11). In addition, the investment would have to be made by either the city council or the European Union (Head of Växjö’s waste department, 2014-05-08) which means that it would not be the waste department which makes the investment and therefore does not need to pay back the purchasing price. Nevertheless, the payback period shows the economic feasibility of implementing a RPS with sensors. In addition, as stated by Guerrero, et al. (2013), updating and increasing technological equipments have a positive effect on the MSWM
even though it includes an economic burden for the municipalities. Sharholy, et al. (2007) and Sujauddin, et al. (2008) explained that significant expenditures are required to provide an efficient MSWC service, which also applies for the municipality of Växjö.

7.4 Constraints Of Changing the Municipal Solid Waste Collection In Växjö

7.4.1 Political Challenges

As stated by Wang, et al. (2012), the MSWM is becoming a priority in municipalities. Moreover, the study of Vidanaarachchi, et al. (2006) showed that the MSWM is supposed to be taking care of by local municipal authorities. However, Moghadam, et al. (2009) claimed that politicians do not prioritize MSWM and have low willingness to implement services related to MSWM compared to other municipal activities. Furthermore, politicians that devote time and energy to a MSWM will have more political influence over those who do not have enough concern (US Office of Solid Waste, et al., 1990). As politicians in Växjö considerably care about their reputation (Head of Växjö’s waste department, 2014-04-11), supporting changes within MSWC might help them get more influence. As previously stated, politicians in Växjö municipality have the responsibility to determine their potential involvements in any MSWM activities (Ibid). Therefore the current politicians in Växjö municipality could be possible constraints regarding changes in the MSWC. Moreover, the head of Växjö’s waste department (2014-04-11) brought up, that usually certain politicians are driven by the belief that implementing new projects related to MSWM induce a rise in the waste fee, and thereby, it might generate a negative impact on the inhabitants mentality as well as hamper their policies reputation. The suggested RPS with sensors in the current MSWC might resolve this constraint since no increase in the waste fee ought to be made.

Additionally, the US Office of Solid Waste, et al. (1990), emphasized in their guidebook called “Sites for our Solid Waste” that the local elections are empowered to change the political complexion of a municipality. Indeed, according to the head of Växjö’s waste department (2014-04-11) the political willingness to contribute in MSWC changes, depending on the local elections (e.g. September 2014), which may
alter the complexity of the political complexion for decision-making. Following this idea, since the politician parties change constantly and in consequence the MSW policies, it is possible to predict that this might represent a constraint towards long term changes in MSWC.

Weng and Fujiwara (2011) specified in their study that it is crucial for the municipalities to make accurate budget plans since the investment cost for MSWM projects might vary due to political influence. Concerning Växjö municipality, the technical committee and the city council are respectively the major players when it comes to decision-making towards the application of MSWC projects in the city (Head of Växjö’s waste department, 2014-05-08). The aforementioned actors are final decision-makers depending on the amount of the budget. When the investment budget is superior to 5 million SEK, the city council is responsible for the decision-making towards further improvements in MSWC, while the technical committee takes care of the financial investment only if the changes are worth less than 5 million SEK (Ibid). In the case of the suggested RPS with sensors, the city council is the decision-maker since the investment costs would be higher than 5 million SEK. Similarly, changes within MSWC in Växjö municipality should be justified with relevant arguments in order to convince the politicians to invest in the changes in the current MSWC.

As mentioned above, the suggested RPS with sensors leads to a reduction in environmental impacts and costs in MSWC. As a result of the cost and environmental benefits, the political constraints can be overcome, and thereby, an adequate budget for the implementation of such optimized RPS is more likely to be approved by the city council. Nevertheless, the city council still acts as a constraint because they make the final decision regarding changes in MSWC. On the other hand, if the city council is unwilling to invest in the MSWC, the waste department can still apply for external funds for instance the EU. Indeed, the head of Växjö’s waste department (2014-05-08), expressed that the municipality is currently seeking for financial funds from the EU in order to be able to finance the MSWC changes.
7.4.2 Socio-Demographic Challenges

Social challenges need to be considered when changing the MSWC. Indeed, Sujauddin, et al. (2008) strengthened the idea that the increased generation of waste is considerably influenced by parameters such as the family size, their level of education but also the monthly income of the citizens. Pandey (2012) emphasized in a study that, the generation and composition of waste have been more varied due to the changes of lifestyles and consumption patterns. Similarly, the head of Växjö’s waste department (2014-04-11), explained that the aforementioned parameters as well as the continuous changes in the population lifestyle have been affecting MSW generation in Växjö.

Rovetta, et al. (2009) emphasized that inhabitants expect substantial efforts from local municipal authorities in accordance with the increase demand for sustainable environmental development of standards of living. However, the municipality of Växjö is continuously working on environmental developments, as stated by the head of Växjö’s waste department (2014-04-11). The environmental expectations from the inhabitants act as a constraint to changes in MSWC. With the RPS with sensors it is possible to reduce exhaust emission, noise, congestion and other environmental impacts. Therefore the suggested RPS with sensors that aim to improve the current MSWC may help the municipality of Växjö to fulfil the goal of maintaining a sustainable environment in the long term and satisfy the environmental expectations from the inhabitants.

Sharholy, et al. (2008) suggested that the success of a changed MSWC depends upon the active participation of both the municipality and the citizens. As Ramos, et al. (2012) mentioned, the population is a part of the solution for MSWC issues and the involvement of the municipality increase the local awareness. A previous change made in the MSWC in Växjö was the separation of waste into two different bins. Despite all the factors that affect the generation of waste and the waste fee, the population of Växjö were well aware of the importance of sorting their mixed and food waste to keep a sustainable environment. As mentioned, currently 80% of Växjö’s households are able to sort their food waste correctly (Head of Växjö’s waste department, 2014-04-11) and
it is forecasted that the inhabitants’ effort will be integrally fulfilled by the summer of 2015 (Växjö kommun, 2014a). Although the willingness of the inhabitants to change might be a constraint for changing the MSWC, the previous case of sorting the waste showed that the inhabitants of Växjö are able to adapt to the changes. Regarding the implementation of the suggested RPS with sensors, it might not change the citizens’ lifestyle. Besides from the households in villas which need to roll out the bins the day of the collection, the changes should not require any effort from the inhabitants.

Minghua, et al. (2009), Pandey, et al. (2012), and Guerrero, et al. (2013) respectively explained that due to the rapid urbanization of the municipalities and the growth in standard of livings, the generation of MSW rate have accelerated considerably in terms of volume and variety. As a consequence, Beliën, et al. (2012) highlighted that an optimize MSWC is exponentially essential. The increase urbanization is as well an issue to handle as it becomes a real concern for local municipal authorities (Rovetta, et al., 2009; Budzianowski, 2012). Similarly, according to the head of planning department in Växjö (2014-04-24), the population is predicted to rise to approximately 96,000 inhabitants in the following twenty years which represents an increase of 12% of Växjö inhabitants in 2013, mainly related to the economic growth and some parameters such as age structure, education and health (Smas et al., 2013). From the head of planning department in Växjö perspective (2014-04-24), the continuous demographic growth in Växjö is a real challenge and will have a important impact on Växjö’s MSWM. The demographic constraint is relevant for changes in MSWC since the municipality of Växjö has to take the increase in waste generation into consideration. However, the implementation of the suggested RPS with sensors could overcome this constraints as it closely monitors and controls the waste generation in real-time and can therefore cope with the changes. The demographic growth could also generate economies of scales for Växjö municipality. Indeed, more citizens lead to a higher amount of bins and a higher amount of sensors. Växjö municipality is likely to have discounts, and thus, save costs by purchasing in bulk. In addition, the savings per bin collected will result in a larger total saving since the number of bins should increase in pace with the growing population. The following figure shows the summary of the constraints that could occur when changing the current MSWC in Växjö municipality.
Figure 39: Summary of the political and socio-demographic challenges

- **Politicians Willingness**
- **Constant change of political parties and MSW policies**
- **Investment Budget Decision Making**
- **Inhabitants willingness to change**
- **Inhabitants environmental expectations**
- **Increase of waste generation**

Source: Composed by authors.
7.5 Cause And Effect Analysis Model

Figure 40: Cause and effects analysis model
8 Conclusions

The purpose of this chapter is to provide a clear answer to the four research questions of the present thesis. Each research question contains an illustrated summary as shown in figures 38-41. This chapter is also highlighting the reflections made by the authors of this thesis regarding the obtained results, as well as underlining the main limitations, which have affected the result of present study. Furthermore, the conclusion chapter is ended by indicating suggestions for further research.

8.1 Conclusion Of Research Questions

**Research question 1:** How can the municipal solid waste collection in Växjö municipality be improved through an optimized route planning?

Figure 41: Answer to research question 1

*The municipality of Växjö can improve the MSWC through an optimized route planning, by implementing the suggested RPS with sensors.*

Source: Composed by authors.

The RPS with sensors is based on the integration of real-time technologies with bin sensors as the core element. The main idea is to change the MSWC from a static to a dynamic route planning. Instead of estimating the quantity and volume of the waste inside the bin through historical data, the suggested RPS has a stochastic perspective and is measuring the content of the bin in real-time through sensors.

In comparison to the current system, the new RPS with sensors minimizes the existing VRP’s: The suggested system solves the SVRP by allowing the municipality to gather real-time data about the amount of waste in the different bins. The operation center software creates routes for each RCV based on the fill rate of the bins. Moreover, throughout those information, the route can be optimized by reducing the total driving distance driven, the time spent on road, the number of stops made and the number of operating RCV’s. Similarly, the suggested system minimizes the CVRP by estimating the bin content and therefore roughly calculating the number of bins the RCV could collect. Moreover, the operation center software can utilise the number of employed
RCV’s in a more efficient manner.

Although, several benefits of the suggested RPS with sensors for Växjö’s MSWC are explained above, this system has drawbacks. With the new system, the VRPTW appears since the system has changed from a static nature to a dynamic nature. In the villas, the customers might need to cope with a lack of information towards the time window when they need to roll out their bins to the curbside before collection. Another drawback of the RPS with sensors is, that the sensors are measuring the volume of the bin content even though the weight of the bin content would be more relevant since the RCV compresses the waste. Nevertheless, the RPS with sensors would still be able to improve the MSWC and thereby the optimize the route planning.

**Research question 2:** How can Växjö municipality and Ragn-Sells AB reduce the environmental impacts of the municipal solid waste collection by optimizing the route planning?

The environmental impacts from MSWC can be summarized as emissions and other environmental impacts, which include congestion, odour and noise. The effects of a RPS with sensors would be a decreasing number of stops, less time spent on the road and less RCV’s in use, which all result in reduced environmental impacts. Although there are no quantitative studies that show what level of reduction in fuel consumption can be expected, it is clear that the optimized route planning will result in a reduction. The emission rates of the MSWC would be decreased due to lower fuel consumption.

As shown in the analysis, it is important to differ between the total emissions and the emissions per ton of waste collected. Since the municipality is growing fast, it is natural that the waste creation is increasing and therefore the total emission rates increases.
However, the major improvements would be a reduction of emissions around the municipality, mainly in the rural areas, as a result of lower fuel consumption per ton of waste collected. The reduction of other environmental impacts would be greater in the urban areas since congestion, noise and odour are less of an issue in the rural areas.

Even though an RPS with sensors is believed to reduce environmental impacts, it is not possible to specify the impact due to the lack of previous quantitative examples. This represents a drawback for the suggested solution.

**Research question 3:** How can Växjö municipality reduce their municipal solid waste collection costs by optimizing the route planning?

![Figure 43: Answer to research question 3](image)

When optimizing the route planning, operational costs such as fuel and maintenance costs could be minimized due to less RCV’s used, shorter driving distance covered and fewer number of bins emptied. In addition, labour costs for the RCV crew could be reduced through employing fewer, but fully utilized RCV’s. The cost savings are expected to be greater in the rural collection areas than in the urban areas, because of the longer driving distance between bin collection points and the associated higher savings in fuel costs. Possible cost savings range between 20% to 40% of the total MSWC costs, resulting in respectively 3,4 million SEK to 6,8 million SEK of annual savings for the municipality of Växjö.

The suggested RPS with sensors would require investments in new technological equipment which involves equipment and installation costs. The total equipment and installation costs for the RPS with sensors, could range from 54,9 million SEK to 65,6 million SEK. However, these costs have to be treated cautiously, since costs for sensors have not yet been fully estimated due to the limited number of prototypes manufactured.
For a more accurate investment calculation, the necessary costs have to be precisely identified and quotations from several waste level sensor suppliers have to be analyzed and compared.

The major drawback of the estimated cost savings is the insufficient reliability of the quantitative data, caused through the lack of relevant scientific information and the usage of quantitative data from sensor suppliers.

**Research question 4:** What are the constraints when changing the municipal solid waste collection in Växjö municipality and how can they be overcome?

Figure 44: Answer to research question 4

Any potential changes in the current MSWC in Växjö municipality involve political and socio-demographic constraints. The main political constraints are as follows: first, the politicians in Växjö are likely to be unwilling to put some efforts in the suggested RPS with sensors since they prioritize other activities of the community. Such improvements in the MSWC consume a lot of time and energy from the politicians who are not likely to put much effort in it. Secondly, the constant changes in the political parties could have an negative effect on the final decision-making in terms of improving the current MSWC. Indeed, the local election may hamper the suggested RPS with sensors implementation since the perspectives of the new political party can radically change the decision-making. Finally, the decision-makers which are the technical committee and the city council, might refrain from getting involved in the process because of the high investment boundaries.
Regarding the socio-demographic challenges, the main constraints that could occur when changing the current MSWC are stated as follows: first of all the population of Växjö municipality is growing gradually which in turn results in an increase of the waste generated in terms of volume and complexity. Moreover, 20% of the population is still not sorting the MSW properly as a consequence of the perceptible changes in their lifestyles. Finally, the citizens of Växjö municipality are expecting substantial environmental efforts from the municipalities to support the sustainable environment.

The benefits drawn out from the suggested RPS with sensors for Växjö municipality in terms of environmental and cost effects might enlighten the politicians in practice to invest in a project that will strengthen their political influence. An eventual support from the European Union should make a difference when it comes to the development of the suggested RPS with sensors in Växjö. On the other hand, despite of the increase of MSW generated, the population of Växjö municipality is well aware of the importance and necessity towards sorting their waste properly. Therefore, any projects such as the suggested RPS with sensors that further the development of a sustainable environment and improve the population standard of living will make the citizens devote their time to contribute to the cause. Additionally, implementing a new RPS with sensors in the current MSWC when the population is growing would lead to generate substantial economies of scales for Växjö municipality.

8.2 Reflections

At the starting point of this thesis, the information regarding the overall process of the MSWC in Växjö municipality were not clear. Afterwards, the authors of the present thesis had the possibility to have in-depth discussion during the personal interviews with the employees from the municipality of Växjö and Ragn-Sells in order to get a full understanding about what the case study would address and what achievements could be done. Moreover, it was also necessary to make limitations and a few assumptions to complete the thesis.

The authors of this thesis believe to have found a good solution towards improving the MSWC in Växjö municipality. The municipality would be one of the pioneers if implementing a RPS with sensors, which would enhance the environmental image of
being a green city. Since little research has been done in the area of RPS with sensors, in particular when implemented in MSWC, this paper could act as a starting point for further interest in the area.

The present thesis is considering few quantitative cost data, either collected from the interviews or from process data since the access to the quantitative information was limited, which make the overall thesis more qualitative. The authors of the thesis are well aware that the collection of the empirical data has been limited in terms of quantitative figures, which in turn might have restricted the obtention of a deepened analysis. Nevertheless, the authors acknowledge that a higher validity and accuracy of data could have been obtained if the participants in the data collection were more willing to share the quantitative information to support the empirical and analysis chapters and thereby the general results of the present study.

Furthermore, an additional boundary is related to the sample size, in terms of participants to interviews involved in the collection of data. Although the authors of the thesis wanted to achieve more personal interviews only two have been proceeded. The authors are well aware that a higher number of participants involved in the data collection might have led to a more accurate and reliable result. Nevertheless, the access to interviewing employees with insight of the case study was limited due to the small size of the organizations.

The authors of this thesis regret not being able to gather more concrete examples about the RPS with sensors implemented in several municipalities, which would have helped the reader to understand even more some of our theory, calculations approaches and more importantly how the RPS with sensors is functioning in real-life.

8.3 Future Research

The authors of this thesis suggest several research areas regarding the implementation of a RPS with sensors to Växjö municipality’s MSWC. Since there is a lack of information regarding the effects of such a system, it could be tested in a small scale in the municipality. The municipality of Växjö could install some sensors at a number of bins and identify real advantages and constraints of this system. The municipality could as
well benchmark and examine the performance and results of the RPS with sensors in order to verify the feasibility of such project.

Additionally, there is a need for gathering more quantitative data regarding the current emission rates and operational costs of Ragn-Sells in Växjö to fully understand the possible impacts an optimized route planning could have. A more precise investment calculation could be made. Nevertheless, the necessary costs have to be accurately identified and quotations from several waste level sensor suppliers like Enevo or SmartBin have to be analyzed and compared, which might be the next step for the municipality of Växjö. Furthermore, an issue stated in the analysis was the constraints regarding the villas since they have to roll out the bins on the day of the collection. Two possible solutions were suggested, although there is still a need for further research regarding this challenge and additional alternatives.
References


Växjö kommun (1992). Avfallplan [pdf]. Växjö: Växjö kommun. Available at: <http://www.vaxjo.se/upload/www.vaxjo.se/Kommunledningsf%C3%B6rvaltningen/F%C3%B6rfattningssamling/Styrande%20dokument/%C3%96vrigt/Avfallsplan%20%C3%B6r%20V%C3%A4xj%C3%B6%20kommun.pdf> [Accessed 2014-03-16].


Personal interviews


Telephone interview

Key Account Manager at Enevo. 2014. Discussion on sensor technology in an optimized route planning system. [Telephone interview] (Personal communication, 12 May 2014 at 3pm).

Email interviews


Head of Växjö’s waste department (per.gunnarsson@vaxjo.se). Sent Monday 5 May 2014: 14.06. [Accessed 8 May 2014].

Key Account Manager at Enevo (petteri.maukola@enevo.com). Sent Monday 12 May: 10:15. [Accessed 20 May 2014].
Appendices

Appendix A

Treatment of Municipal Solid Waste in Växjö

Source: Composed by authors based on Växjö Kommun, (2014b).
Appendix B


Waste reduction
- Waste management hierarchy (Reduce, Reuse, Recycle, Incineration, Landfill).
  - Reduce waste main focus?
- What kind of bins? How do you buy bins? Do the bins already have the RFID included?

Regulations
- Household waste fee, municipal waste regulation and local waste plan
- Are there any future regulations/laws that require changes in your waste management? (2012: National goal on 30 % collection of organic Waste to biogas or composting)

RFID
- When did you implement the RFID system?
- Is RFID applied to optimize the route plan of the trucks?
- Have you considered using sensors application in the bins to optimize route planning?

Costs
- Would you implement a pay-as-you-throw system for reducing household waste? The households would pay based on the amount they throw away which can encourage reduction of waste (You already have made the necessary investments)
- How do you pay the contractor? Is it based on the number of bins, kg, fixed amount?
- What main costs/fees are expected to increase?

Problems
- What are the issues that you face in the waste collection?
- Any general long-term goals with waste handling that you find challenging?

General questions:
- Do you benchmark with other municipalities?
- Are there any requirements/ wishes of households, which could improve waste management?
- “Collection of household waste is “USUALLY” carried out by contractors”.
  - If it is not Ragnsells AB who does the pick up?
- Have you had any waste reduction projects?
- Have you ever considered to have bins different colors? (to distinguish the types of waste)
- Relationship issues
Appendix C


General company questions
- What kind of waste are you handling for Växjö kommun? Which other waste are you handling in Växjö contracted by other organizations.
- How many trucks and employees do you have for Växjö?
- What are the issues that you face in the waste collection?
- Are you only working for Växjö kommun or are you also involved in recycling of material that falls into the producer responsibility?

RFID
- Who implemented the RFID, Ragn-Sells or Växjö kommun?
- Since when do you use RFID?
- Is RFID applied to optimize the route plan?
- Who buys the bins, municipality or contractor? Do the bins already have the RFID included?

Optimized route planning
- Have you had any route optimization projects in Växjö? Are you planning to optimize further?
- Have you considered other sensor applications? If yes why don’t you use it? if no, explanation of the benefits

Regulations
- Any general long term goals with waste handling that you find challenging?
- Are there any future regulations/laws that require changes in your waste management?
- Do you have any local regulations to support waste reduction in Växjö?

Costs
- Do you benchmark with other waste transport companies?
- What main costs/fees are expected to increase?

Follow up
- Could we observe how the route planning works?
- Could we come for a second meeting?
Appendix D

Petteri Maukola. Key Account Manager at Enevo. 2014. *Discussion on sensor technology in an optimized route planning system*. [Telephone interview] (Personal communication, 12 May 2014 at 3pm).

1. How does the sensor works (SIM card needed)?

2. Any previous examples where they implemented the system at the bin level in a municipality (What have been the savings such as reduced kilometer distance, fuel consumption)? Is it possible to get documents?

3. How does the household know when the bin will be collected?

7. Any recommendations when suggesting such a system to the municipality to increase the feasibility of this project?

8. Any other constraints when implementing these sensors?

Appendix E


1. What are the effects on route planning (empirical examples), especially regarding cost savings and environmental impact reduction?

2. Can the municipality get (financial) support from the EU?

3. Prices for purchasing and installing the sensors (per bin)?
Appendix F


1. How do you forecast the demographic growth?

2. Do you have numbers about the increase of population?

3. Regarding the forecast what would be the future necessities?

4. What are the prognosis for the next twenty years?

5. How does the municipality handle the planning development in the rural and urban area?

6. Could you forward us documents related to municipal solid waste management?

7. To what extent do you think the continuous demographic growth is going to affect Växjö municipality?
Appendix G

Martin Duru., martin.duru@hotmail.com, 2014. Discussion on current route planning system (focus on costs and financial support). [Mailing of questionnaires] Message to Per Gunnarsson, Head of Växjö’s waste department (per.gunnarsson@vaxjo.se). Sent Monday 5 May 2014: 14.06. [Accessed 8 May 2014].

1. Do you have any financial operational data, such as costs per bin/tonne collected?

2. How many bins do you have in the rural area and how many in the city?

3. It is possible to have Avfallsplan Växjö Kommun 2014-2020? For instance Alvesta kommun has: http://www.alvesta.se/PageFiles/29858/Avfallsplan%20version%20samr%C3%A5d.pdf

4. If the politicians don’t approve the budget for an investment, do you have other financial supports, EU for instance?

5. Who is the final decision-maker to accept an investment project?

6. How do you control Ragn-Sells with the RFID-system. Do you have any data about their performance?

Appendix H


1. When and how often do you unload the truck in one shift? Is the disposal trip considered when planning the route?

2. What is the capacity of each vehicle? (Statistical) data or key figures about the collection of waste and the vehicles such as fuel consumption, utilization of vehicles, fuel expenditures, emission rates.
Appendix I

Communication framework between the RCV and the central control (GIS) after the RCV driver activate the black box

Source: Hannan et al. (2013).