Efficient and connected transport systems

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Author Joakim Wigström
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Content

1. Summary

Today, approximately 30 million tonnes of waste are generated in Sweden (excluding the mining industry), which creates a situation of excessive transport. This situation is not only a concern for waste companies, in the long run excessive transport may contribute to

damage our environment, which concerns to everyone. An efficient waste logistics is a key factor for enhancing environmental responsibility in Swedish waste companies.

There is a great potential for improvement on this topic. Some of the important areas to look at are filling rates in waste containers and vehicles, route planning and selection of vehicles for collection of waste containers. For waste generators and collectors having this information in the right time would improve the way in how logistics processes are performed now.

The purpose of this feasibility study was to develop a concept for waste logistics optimization. The concept depicts a new system for measuring the filling rates in containers and ensuring that the information can be used in transport planning. The plan for the new system was to combine sensor IoT technology with AI. Sensors would be used to measure the content weight and position for the waste container. This information together with the container size and the kind of material waste would be used by AI algorithms. For the digital solution, three key parameters had been identified:

- Long battery time to obtain a safe solution that requires minimal maintenance.
- Sensors must be able to determine where waste containers are located.
- The solution must have a low investment cost as well as running cost.

Part of the methodology in this study was the identification and evaluation of weight sensors. Several solutions in the market were tested in a laboratory environment. The testing was performed following the manufactured specifications. Regarding the position sensor, the company TRAKK was in the final phase of its development. Their technology enabled a sensor with a long battery life, connected to a so-called narrowband IoT network. This would allow efficient energy usage by the devices. The AI algorithms would be based on data from the proven sensor technologies, and the calculations would be carried out using a cloud-based solution. The result showed that the current state for the IoT technology is mature enough for the positional sensor. For weight sensors on the other hand, it is not. This is due to technical challenges and complexities that increase cost.

Overall, the study showed that improving waste transport planning has potential. The study has created knowledge about the needs of a future waste transport planning system. A logical next step is a continued project to create an effective tool to facilitate efficient planning of waste shipments possible including position sensors provided by TRAKK and model for savings assessment.

2. Sammanfattning på svenska

I Sverige genereras årligen cirka 30 miljoner ton avfall (exklusive gruvindustrin) vilket skapar ett omfattande transportbehov. En viktig del i att åstadkomma hög transporteffektivitet är att säkerställa höga fyllnadsgrader, vilket inom avfallslogistiken handlar om att fordon som transporterar avfallet nyttjas effektivt och att avfallsbehållare är fulla när de hämtas hos den som genererat avfallet. En effektiv avfallslogistik har stor betydelse för miljön eftersom väl nyttjade fordon med god fyllnadsgrad i avfallsbehållare betyder minimal klimatpåverkan förutsatt det existerade transportbehov (avfallet måste tas om hand)

Tidigare studier visar på att det finns en stor förbättringspotential gällande avfallslogistiken avseende fyllnadsgrader i avfallsbehållare och i fordon, ruttplanering och val av fordon för upphämtning av avfallsbehållare. En stor anledning till att avfallslogistiken ofta brister har att göra med bristande informationsdelning mellan avfallsgenererare och avfallshanterare. En tilltalande lösning på dilemmat skulle förstås vara att ersätta det manuella informationsutbyte mellan avfallsgenerare och avfallshanterare med ett digitalt informationsutbyte där fyllnadsgrad i behållare registreras direkt till avfallshanteraren.

För en digital lösning som mäter fyllnadsgrad i avfallsbehållare och skickar denna information till avfallsbolag och transportörer ska användas i stor skala i Sverige har vi genom samtal med avfallsbolag och sensorutvecklare identifierat tre parametrar som måste uppfyllas: (1) En lång batteritid för sensorer, (2) systemet måste kunna bestämma sensorernas position (3) lösningen måste ha en låg investeringskostnad samt driftskostnader.

Med tanke på dessa identifierade behov var syftet med denna förstudie att utveckla ett koncept för att mäta fyllnadsgrad i avfallsbehållare som bygger på IoT- och AI-baserat Proof-Of-Concept.

I förstudien kartlade vi avfallstransporter i ett antal branscher, bygg-, fastighetsbranschen och industrin. Det framkom att fyllnadsgrader ligger mellan 10-100% procent, beroende på avfallstyp och marknadssegment, och därmed finns det en stor potential att öka fyllnadsgraden genom automatisk mätning. Vidare visade det sig vara svårt att veta var avfallsbehållare befinner sig någonstans vilket i flera fall ger upphov till onödigt arbete. Även detta ställer skapar behov av automatisk spårning av position i behållare

De tekniska kraven för de nödvändiga IoT sensorerna samt vilken sensorteknik som skulle kunna uppfylla de tekniska kraven utvärderades. Funktionskraven var att mäta fyllnadsgrad samt positionsinformation hos avfallsbehållare kombinerat med robusthet och låg energiförbrukning. En av de viktigaste slutsatserna är att viktmätning av containrar med hjälp av IoT-sensorer är svårt den tekniskt svåraste parametern att mäta. Med nuvarande tillgänglig teknik är detta inte möjligt att uppnå på ett konkurrenskraftigt sätt. Ett sensorviktsystem skulle ha en oöverkomlig kostnad eller drabbas av problem relaterade till att nå den nödvändiga drifttiden.

Fokus i projektet flyttades därför till att utvärdera möjligheterna för ett system som enbart beaktar positioner hos transportbehållare. Vi samlade in data med positioner av containrar, då dessa hanterade av en avfallsentreprenör, för att kunna utveckla och utvärdera algoritmer.

När datainsamlingen inleddes stod det klart att det var nödvändigt att basera datainsamlingen på insamling av positioner på transportbilar, i stället för själva containrarnas positioner. Trots detta gjordes bedömningen att det skulle vara möjligt att få en stor datamängd eftersom uppgifter samlades in från ett litet antal transportkort som hanterar ett mycket större antal containrar. Under dataanalysen konstaterades det dock att det var svårt att bearbeta uppgifterna för att ta fram nödvändiga data, som beskriver containercyklerna för leverans och tömning. På grund av dessa datarelaterade svårigheter kunde inte arbetet med utveckling av algoritmer slutföras.

Svårigheterna konstaterades bero på komplexiteten i de insamlade uppgifterna. Denna spårades genom intervjuer med förare och orsakades av att mönstret för hantering av behållare varierar från plats till plats och från tid till annan, då förarna minimerar tid för på och avlastning samt körsträcka, två ofta motstridiga krav. Viktiga faktorer inkluderar: (1) Avstånd mellan kund och återvinningscentral (2) Antalet containrar som behöver hanteras i kundens lokaler (3) Den tillgängliga last-ytan hos kunden (3) Andra kunder i närheten (4) behållares storlek och modeller (5) öppettider hos kunden.

En av de viktigaste lärdomarna från denna studie är att det är viktigt att få en bättre förståelse för dessa faktorer, som ska beaktas när förare hanterar lastning och tömning av containrar. Faktorerna har en viktig roll att spela i utformningen kraven för ett system för effektiv planering av avfallstransporter. Både när det gäller att bestämma riktlinjerna för data som krävs och vad algoritmerna skall optimera.

Sammantaget visade studien att en förbättring av planeringen av avfallstransporter har potential. Studien har även skapat kunskap om behoven av ett framtida system för planering av avfallstransporter. Ett logiskt nästa stegär att bygga vidare på den kunskap som erhållits från detta projekt och skapa ett verktyg för att underlätta en effektiv planering av avfallstransporter- Ett sådant verktyg skulle omfatta följande: (1) Positions sensorer från TRAKK som utvecklats och testats i projektet (kommersiell lansering 2021) (2) Modell för att bedöma potentiella besparingar (3) Insamling av data och algoritmer som fångar upp aspekter av åtgärder på kundplatser , så de viktiga faktorer som identifierats beaktas (4) Metod för att förutsäga graden av fyllning av avfallsbehållare.

I ett fortsättningsprojekt behövs ett annat sätt att mäta fyllnadsgrad, eftersom problemet med automatisk bestämning av fyllning inte löstes i projektet. Dessutom måste en rimlig metod tas fram, för att samla in information om vad som händer hos kunder, vid tömning/hämtning etc.

3. Background

Today, approximately 30 million tonnes of waste are generated in Sweden (excluding the mining industry), this creates a situation of excessive transport. An important part of improving transport efficiency is ensuring high filling rate in waste logistics. This means that vehicles for transport waste are used efficiently, and waste containers are full when collect the generated waste.

In addition, waste recycling is depending on collection; so, the more efficient is, the better conditions for recycling are. This follows rules in waste hierarchy: primarily minimize the waste generation, followed by reuse, recycling, energy recovery and ultimately landfill.

An important consequence of efficient waste logistics is the implication for the economy, efficient waste logistics means reduced transport costs for waste managers and thus reduced waste management costs for the waste generator (e.g., vehicle manufacturers component suppliers, construction contractors).

Previous studies showed that there is a great potential for improvement in waste logistics: (1) the filling rate of waste containers and in vehicles, (2) the route planning and (3) the vehicle selection for collection of waste containers (Kurdve et al, 2018). One big reason for waste logistics deficiencies is the lack of information, in the right time this can be shared between waste generators and the transport planning unit to improve waste collection (Thunberg et al, 2018). In conversations with waste managers, they expressed the opportunity for a better filling in containers and for improving the picking up from direct orders, orders are usually done in short notice. Practical experience fits well with the research. Regarding to waste picking up, a study on waste logistics in construction projects concludes that in most collections, only one waste container was collected at a time; even though there were good opportunities to come up with a larger vehicle and bring more waste containers at the same time (Kurvde et al., 2019). Even more, another interesting finding was the filling rate, in more than half of all waste containers, it was below 50%. An appealing solution to the dilemma would, of course, be to replace the manual exchange of information for a digital approach, this would relieve manual registration between waste generators and waste managers.

Currently, there are several solutions available to measure filling in waste containers. Some examples are Smartbin (https://www.smartbin.com/), Enevo (https://www.enevo.com/) and Acconeer (https://www.acconeer.com/) solutions, this last one, measures the filling rate with a sensor (IR or ultrasound) located at the top of the waste container. Another example is bintel (https://bintel.se/slider/) which has a manual solution where people indicate if the container is full by pulling a 'handle' aside.

Prior to the project we had conversations with waste companies and sensor developers, then, we identified three parameters that must be met for a digital solution:

- **Power:** The sensors must have a long battery time to obtain a safe solution that requires minimal maintenance.
- **Position:** Sensors must be able to determine where waste containers are located.
- **Price:** The solution must have a low investment cost as well as running cost, the waste industry is under severe price pressure.

Given these identified needs, the purpose of this pre-study was to develop an IoT and AI based concept for a new system. This system would measure the position of a containers as well as the filling rate. After the measurement, the information can be sent to waste companies and transporters, then AI optimization techniques can be applied for an efficient waste logistic. Later, the project results could be used on a large scale in Sweden.

4. Purpose, research questions and method

4.1 Purpose

The purpose of this pre-study was to develop a concept for waste logistics optimization. The concept portrays a new system based on measurements for filling estimation in waste containers to improve transport planning. In a continued project, the goal is to further develop the concept into a finished product and thus to contribute to improve waste logistics in companies; and eventually in time, to reduce environmental impact from the Swedish waste industry.

4.2 Research questions

The purpose of the study was to answer the following questions.

- How is the current situation in waste transportation and market? What kind of problems are they facing?
- What is the efficiency for current transport solution, in terms of filling rate?
- What technologies can provide sensor data in terms of: (1) Filling rate estimation in containers, and (2) positional information.
- How physically robust sensors are? What are they characteristics (i.e. Price, energy consumption)?
- What type of AI algorithm will be able to estimate the filling rate in containers, based on sensor data?
- What type of AI algorithm is suitable for improving planning in waste logistics? Here the important part is how to combine the filling estimations in containers and logistic information in form of positional data.

4.3 Method

The project goals were organized into the following four work packages (WP) each one focusing on different requirements.

4.3.1 WP1: Understanding of the current situation

The purpose of AP1 is to 1) gain an understanding of the need for the solution and the environment in which it is to be implemented. 2) map waste flows at participating companies, i.e. which material fractions are collected, in which volumes, in which waste containers and with which degrees of filling.

To answer part one of the purpose, we conducted interviews with eleven companies, ten project partners and an external actor. CargoSpace 24, Suez, BewlSynbra, Ragn-Sells, NCC, Castellum, CMT, JOAB sales and Trakk telematics solutions and Kretslopp och Vatten. The interviews took about 45 minutes per respondent and were semi-structured. Due to the Corona situation, the interviews were conducted via Teams or telephone. The issues addressed during the interview concern the need to be able to measure the filling rate in waste containers, challenges, and opportunities.

To answer part two of the purpose, we have interviewed the project partners who generate waste and those who handle waste (Suez, Ragn-Sells, Renova, NCC, Castellum). The issues have touched on how waste management is carried out and how waste management services are structured. We have collected waste statistics from the project partners who handle waste regarding the construction industry, industry and the real estate industry (i.e. industries that are represented in the project group). The waste statistics that we have been interested in are which material has been collected where and transported where, in what volumes, in which load carrier and when in time. Regarding load carriers, we have focused on container collection and compactors because it is easier to find collection points (customer / address) and read all empties for a certain period for containers and compactors than for containers.

For the real estate industry, we have collected statistics from 22 customers from a waste contractor with a time interval of six months. For the industry, we have collected statistics from 421 customers during the period 2018-10-01 to 2020-09-30 from a waste contractor. From construction, we have collected statistics from two waste contractors. For one of the waste contractors (A), we have received statistics for 22 projects during the period 2016-03-15 to 2019-02-06. For the other waste contractor, we have received statistics for 1727 projects during the period 2016-01-01-2020-09-30. The reason why we have chosen a longer time interval for construction than real estate and industry is that it is important to get information for the entire project, from start to finish.

Based on the statistics, we have calculated 1) Max weight per container and material. 2) Filling rate per container and material. These two dimensions are essential to be able to set up a solution where a sensor should be able to determine when a certain container loaded with a certain material is to be emptied. In calculations, we have used pivot tables. For data sets from the real estate industry and data sets from waste contractor A (the construction industry), data have been cleared from outliers. We have manually gone through all the maximum weights per container and material and since there was an outlier, in many cases the second largest value was taken as the maximum value. For datasets from industry and datasets from waste contractor (B), we have not cleaned out outliers, which has meant that filling rates from these datasets are lower than for others.

4.3.2 WP2: Sensors

The purpose of WP2 was to develop a requirement specification for a battery-efficient sensors in a networked system, this includes the position sensor and weight sensor. If possible, it would be good to create a prototype. Since the result requires evaluation of practicality, integrity of sensors, and robustness of measurements, this work package required real lab tests as well as scaled up tests on real containers. In a similar manner the function of positional sensors required live tests.

4.3.3 WP3 and WP4: Data collection and Algorithm development

The chosen methodology in this WP was the one more commonly used for AI projects: (1) Data collection, (2) Data visualization and inspection, (3) Further processing and validity checks, (4) Implementation and training for candidate algorithms, and finally (5) Performance measurement by evaluating accuracy of prediction.

5. Objective

The goal of the project was to develop an IoT concept for optimizing waste logistics, the concept is based on an AI solution. The idea is to measure the filling rate in waste containers and use this information for optimizing waste transport planning. As a continued project, the goal is to further develop the concept into a product. Having a better waste planning, the end goal is to contribute in reducing the environmental burden generated by the Swedish waste industry.

4.3.1 WP1: Understanding of the current situation and market

In a current situation analysis, existing waste streams from participating companies in the project would be mapped. This working package is about gaining an understanding of what material fractions are collected, in which volumes, in which waste containers, type of transport, transport booking, initial filling rates when waste containers are leaving waste generators and transport efficiency. Specifically in transport efficiency, it is good to know the choice of vehicle, filling rates in vehicles during service, and route planning. This analysis stated an understanding of the needs and environmental conditions to formulate and design the solution, in terms of design it gave the guidelines for identifying the appropriate flows to train the AI algorithms in WP4.

4.3.2 WP2: Sensors

The objective of WP2 was to develop the requirement specification for a battery-efficient and connected sensor system. This includes the position sensor and weight sensor.

- Position sensor: The participating company TRAKK would further develop and evaluate its current position sensor's precision, battery use and durability in a real-world environment. The evaluation end goal is to create a requirement specification, this will contribute for further development.

- Weight sensor: This part comprises the identification for possible weight sensors required in the solution. It may be the case no good solution is found, therefore the specification of a new sensor would be created. The methodology for this identification is at first through searches and interviews; and later, a comparison of sensor's performance and requirements to find the appropriate weight sensors.

An additional objective of WP2, not described in the application text (but referred to in later WPs) was to create a prototype of the weight/position sensor which would be used in the following work package.

4.3.3 WP3: Data collection

The objective of WP3 was to create a dataset that can be used in the development of AI algorithms. This data would be collected in two different ways: lab and real environments, this last one would give important information about the real conditions where the final product would be used. Sensors would be installed in both environments and data would be collected continuously throughout the project.

In the original plan, a dataset containing both the position as well as weight of containers would have been created. But through the research in WP2, it was found out that for the solution is not possible to have a weight sensor that meets both competitive price and robustness, so no weight sensor prototype was created in this WP. Therefore the planned data collection related to this could not be performed. Instead, the objective in this WP was shifted to focus in collecting positional data from waste containers in a real-life situation. Still, the idea was to keep the same project goals. It was planned to afterward combine positional collected data together with simulated values for detecting weight. The combined data would create a "complete" data set for algorithm development.

4.3.4 WP4: Algorithm development

The objective of WP4 was the development of an AI algorithm. This algorithm is based on waste vehicle information: container filling estimations and positional data. The scope was at the Proof-of-Concept (PoC) level because large amounts of data were expected to be required in a real scenario. This algorithm would represent the foundation model for a larger project.

The goal in this WP was to produce:

- Architecture of an AI model which depend on statistical quantities of the generated data in WP3.
- Evaluation results of model, tested on data from WP3.

6. Results and deliverables

6.1 WP1: Understanding of the current situation

The following section describes AP1's results.

6.1.1 Need for an automated solution for measuring filling rates

Many respondents believe that an advantage of being able to measure filling dates is to create a better transport efficiency and thereby get a cost saving and reduced CO_2 emissions. In addition, it will hopefully create better planning for the waste contractor. For example, some customers call in / place orders in the customer portal and request picking up of container very late, which results in emergency calls. Alternatively, the customer wants their waste container emptied before a weekend and then the container is not full when the waste contractor picks it up. Many of the respondents also think that an automated solution for measuring filling rates in waste container will eliminate/reduce the need of customer to call in and place orders.

An automated solution for measuring filling rates in waste containers can also be used as an important information source that can be used for dimension of different waste rooms in family houses and to build correctly in the future. Some respondents speculate whether the information could be used to study the correct use of vehicles. This information could possibly be used in product development of new vehicles.

Several waste contractors say that they do not always know where the waste containers are. A dilemma is that many customers move the containers and then the waste contractors lose control. *"Keeping track of where we have our containers is an important part for us"*, stress one of the respondents. The consequence of not knowing where the waste container is located is that the waste contractor risks picking up the wrong container or that the contractor arrive with the wrong vehicle to pick up the container. *“We search to find techniques so we can keep track of our containers. The solutions today are too expensive, but we really need to know where our containers are located*”.

6.1.2 Where is the need of the solution the largest?

The respondents have somewhat different opinions on where automated solutions for measuring filling rates are most needed. Some respondents think that the solution is interesting for compactors, containers, and bins. However, most respondents think that container is most interesting. *“When it comes to bins, you typically drive a route and empty up to 200 bins before driving to a sorting facility/hub. Thus, as one drives along one takes the opportunity to empty at the same time”,* says one respondent. This is not the case with containers that should be picked up when they are full. In fact some respondents stress that the logistics may even be made more difficult if you empty bins “on demand” (when they are full) as the routes are then constantly changing, which can lead to other problems such as drivers not learning the route. More important here is rather the dimensioning of the bins, according to a couple of the respondents.

Those who believe that automated solution for measuring filling rates is interesting for bins stress that it can facilitate route planning. It may be that waste contractors drive too often and then it might be better with demand-based emptying. However, it is perhaps most interesting in cases where you have a common waste management solution such as in apartment buildings, single bins probably do not bring much profit.

The respondents emphasize that the solution is suitable for waste from industries as well as household waste. For collection of household waste, it is primarily at unmanned collection point such as “Återvinningsstationer” that the solution would be suitable, as there is no personnel that can keep track of when waste containers need to be emptied. One respondent believes that the solution could be interesting for underground containers. *“In household waste, it is common to run subscriptions with emptying 1 / week. If you discover that it is often half full or often overcrowded and it is a long-term trend, you can change frequency, but there is potential with sensors here”.*

It was noted that there are differences between different industries. Construction is mobile, i.e., the project changes from time to time. Industry is stationary, i.e., the production site and supply chains are the same. In a stationary business, it is probably easier to make the solution work, since it is easier to forecast how long it takes to fill the container. In construction, it is difficult to know when you must pick up the container after you receive a notification. On the other hand, several respondents believe that the need of the solution is largest in the construction industry as it is characterized by irregular flows and lack of space.

Many respondents emphasize the cut-off point as something that is important to consider when implementing the solution. In compactors one typically uses a cut-off point at 75% of filling rate, i.e. when the compactors is filled up at 75% an alarm tells the customer to place an order to the waste contractor. According to respondents, it is important to not have a too high cut-off point as it can result in negative consequences for the customer, such as the waste container being too full to be used until it is picked up. It is possible to imagine getting a signal at 25%, 50% and 75% filling degree.

6.1.3 Barriers to implementation and use

- The cost is as expected an important factor.
- Limitations of sensors. One challenge is the so-called "plank example", i.e. when plank sticking up in the waste container tricking it into believing that the waste container is full, even though there is a lot of space left.
- Correct business model. It is important to create a balance between all parties where everyone can win; along with this, it is important to consider environment improvements with this project. It is more likely that needs-adapted emptying ends up with a fewer number of transports; this could be a problem because in most cases waste contractors charge per emptying, treatment and rent; even more, this adaptation could lead for a contractor to lose some revenue. There are examples where the waste contractor charges a fixed cost for a waste solution and

in these cases the waste contractor would save money by emptying when it is full. In these cases, it is also important to rethink the business model, where profits are shared with the customer (the waste generator) in the form of cost savings.

- Today, the response time in construction is typically 24h, but large customers who call before 9am should have emptied the same day. It may be important to settle in agreements how long the response time should be.
- An additional barrier is for the parties to trust in technology and not calling to ensure someone comes and pick up the full waste container. Many also say that regarding to existing systems, there are difficulties with integration.

6.1.4 Waste management in the construction business

For the construction industry, Just-in-time (JIT) usually applies to emptying or so-called bidding. JIT or bidding means that the waste container (usually container) should be emptied for a certain time after the customer has called in or placed their order in the customer port numbers. Often it is a matter of emptying the container on the same day. Sorting takes place on site at the construction site and the customer sorts into several fractions directly.

In the construction industry it is often crowded, and the project may only have room for three containers but is really in need of eight. The consequence is that you need to empty often, and it is not uncommon for the customer to change materials that are thrown in the container. This is a problem because the waste contractor goes out with a vehicle with the intention of emptying, for example, gypsum, but then it is combustible in the container instead to be driven to another place (heating plant instead of pre-treatment).

The result shows that that the construction projects sort a number of fractions: combustible, landfill, corrugated board, inerta masses, plaster, electronics, mineral wool, mixed scrap, brick, wood, concrete, plaster, stretch film, soft spot, etc. The filling rates range from 0.1 to 1.0. It is clear that maximum weights differ for the same waste container depending on the material, plaster weighs a lot and mineral wool a little less, for example.

It is difficult to identify any material that holds higher filling rates than others. For fixed routes, the time of emptying is prioritized (not filling rates). Other containers that are emptied of on demand are therefore more interesting for the project because the filling rate of these containers is of greater importance.

Mixed fractions can contain inert materials as well as combustible ones and the filling rate can thus differ greatly for different pick-ups. Sometimes mixed mkt contains inert material of heavy weight. At other times very large bags that do not weigh so much. In construction, waste changes a lot during the project, which means that filling rates for mixed are very different.

6.1.5 Waste management in the real estate industry

In the real estate industry, fixed rounds are common, i.e. picking up waste on a weekly basis. Vessel emptying is quite common (more common than in construction and industry) but container solutions are also available. The customer sorts directly into several fractions. Collection/emptying often takes place in a garbage room and some waste contractors offer full service where they provide staff who clean and keep up. Several waste contractors offer full service where they take care of everything on site.

Subscription services are often used where transport, processing, handling is clustered. However, they can see how much was collected and what was transport/treatment. The statistics clearly show that maximum weights differ greatly depending on the material loaded into the waste container. Corrugated board, soft plastic has typically low maximum weights. Filling rates range from 0.4 to 1.0. It is difficult to point out any material as better than any other current filling rates. Plastic comes high but it is also a small fraction in terms of volume. In the statistics we can see that filling rates for open containers are quite high and one reason for this may be that they have been overloaded because they are just open. Compactors give a little lower rates and one reason for this is that they are often on schedule pickup according to the waste contractor that gave us access to the statistics.

6.1.6 Waste management in the industry

Depending on the industry, the type of waste container looks a little different, it can be containers, compactors, and containers. Often fixed rounds are used, and waste contractors sometimes need to go into the workshop and pick up containers. The customer sorts waste into several different fractions. It is typically more hazardous waste in industry than in the construction and real estate industry. Some waste contractors offer full-service solutions where they take care of everything on site, e.g., pick up waste in the workshop and clean.
In industry, the challenge is more linked to internal handling, once the waste has come out of the factory, there are no major problems. Getting the waste out of the factory, on the other hand, is not always so easy. Customers sort out many different types of materials such as food waste, asphalt, aluminum, concrete, electronics, scrap, plaster, hard and soft plastic packaging, metal packaging, wood, scrap, cable, office paper, soft plastic more. Filling rates range from 0.1-1.0 and it is difficult to distinguish any material that has higher filling rates than others.

6.2 WP2: Sensors

The goals of WP2 were to investigate if it is possible to create a sensor unit for measuring position and weight. The weight unit would be used either mounted under containers for weight measurement, or alternatively as IR-based solution inside containers. In this WP, the aim of evaluating sensors for measuring containers filling rate was reached, first indoors and later in real hardware tests.

In the WP weight sensors were first assembled. As we said before, they were tested initially indoors. The function, and requirement fulfillment were validated. The test showed the capability for sensors to measure the container full weight and also to detect container “touchdown”, this last one is an event that can be used to tell if the container was unloaded from a transport car.

Following this, an outdoor real setting was performed for both development and preparation for WP3. A test field emulating a usage cycle was performed. This test involved transports back and forth between a factory and recycling. Two containers in the test were equipped with weight and position sensors. At the end, it was found that the position part of the sensors worked as designed.

However, there were problems related to the weight sensing hardware; and at the same time, the users were not able to provide relevant information about weigh. No useful measurements or meaningful assessment could be drawn from the collected data. One conclusion is that larger field tests would be required, and it could be useful to have dedicated staff for this activity, this people could make a better assessment for where sensors should be used and for what benefit.

One main conclusion about the original hypothesis is that the functionality can be achieved but difficult to implement, and this is because multiple weight sensors are required for an accurate weight measurement. This set increases both the cost and complexity of the original solution. Today, the components and systems available make the cost for such system prohibitive.

During handling, the subjected forces are also considerable, which contributes to increased complexity and price. Tests made with optical sensors (IR) showed other challenges, related to reaching the uptime required by the customers, as a result of the power requirements for these sensors.

Due to these results and the problems for weight measurements, the subsequent work package (WP3 and WP4) had to be adjusted.

6.3 WP3: Data collection

The goal of WP3 was to create conditions for the subsequent work package (WP4). Some of the goals of WP3 were adapted, this was done because as previously described, the data collection was changed into focusing on events related to waste containers, i.e., data of positions, and time for delivery and emptying. The data collection was performed in collaboration a member if the project group which is a transport contractor.

At the beginning of the study together with the partner, it was found that it was not feasible to control the geographical destinations of the waste containers, this due to circumstances of logistics and way of working. Because of this, the plan of using the positional sensors being developed by TRAKK, could not be used for data collection. The main problem was related to limitations in the coverage provided by the current LoRa base stations, it was mandatory for the sensors to be in contact with those stations. The work turned to using the only feasible option remaining - commercially available long battery-life GPS devices. Due to the perceived risk of vandalism and theft of these, it was decided to instead place the GPS-devices in the transport cars as they constitute a safe environment.

Data from all the company's transport trucks was collected over a period of five weeks and compiled into a one dataset. This dataset contains information about time and visited locations. Based on the analysis for this data, the plan in WP4 was re-create a complete data set. We called it "container centric" data, and it would hold information about trace of position, time at, filling and emptying, and travel distances. Despite the limitations of the data collection, the assessment opened the possibility for getting a large dataset, this is because data was collected from a small number of transport card which handles a much larger number of containers.

6.4 WP4: Algorithm development

The goal of WP4 was to create and evaluate possible algorithms that can predict when a waste container is ready to be emptied. This approach can be the basis for a model in a later project. As mentioned above, the focus of the work package was changed to evaluating algorithms based on "container centric" data, this data would cover the container cycle for delivery and emptying. As it was mentioned before, the data contains positions and times as well as other relevant information such as time and distance of transport, simulated weight indications are included as well too.

To obtain the desired "container centric" data, the raw data was analyzed and processed in several stages. In brief, positions for drop-offs and pick-ups were selected by recording the positions where cars had stopped at. Through cluster analysis, customer locations were identified from these. Hundreds of such places were identified. The final step was to determine if a customer stop represent a container delivery or emptying. The method for determining this was a rule-based approach, this would be based on assumption of a sequence where a visit to a customer would be followed by a visit to a recycling station. By manual inspection over some cases, it was validated that the rule-based approach was correct, although this is not sufficient, and this final step was proven to be difficult to accomplish, and we concluded it was not possible to complete within the project budget.

The causes for the complexity in data were traced through interviews with drivers. The pattern of handling containers varies from place to place and from time to time. The drivers' mission is to minimize both loading time and mileage, two often contradictory requirements. The most effective strategy for routing and container handling varies from place. Here follows a summary of the most important factors in these matters:

- Distance between customer and recycling the center. When it is short, it may pay off to drive extra turns between these. The extra milage is compensated by an efficient and minimized loading time. When the distance is longer, however, it pays to bring empty containers to the customer and replace them with full ones, which are then transported onto the recycling center.

- The number of containers which needs handling at the customer's premises also affects which strategy is most efficient.
- The available loading area at the customer. If it is limited, extra turns to the recycling center might be required.
- Keeping in mind other several customers at the same time, can often result in strategies for delivery and emptying which save time and milage.
- Containers come in different sizes and there are different models. Depending on the type of the transport car is able load different number of containers onto the car simultaneously.
- The route and its order of execution are also affected by other factors such as opening hours at the customer's premises.

One of the most important lessons from this study is a better understanding for these factors. They are a key part when creating the requirements of a system in efficient waste transport planning; also, they give the guidelines for both choosing the data and what to optimize for, and support on how to best integrate the system into decision flow that supports a logistic planning system.

In parallel to the data processing, the algorithm development was started. As a first step, a mathematical model for assessing the theoretical possible savings (time, cost, traveled distance) was developed. The model considers the emptying events together with their associated traveled distances to customer and recycling plant. By relying on the data for the average filling rate from WP1, the model would be used to calculate estimates of the potential for savings, which is one of the research questions.

Predicting when a waste container is ready to empty was the main goal for this WP, however the following steps for creating the corresponding prediction algorithm were not completed due to the data related difficulties.

6.4 WP5: Project coordination

An application for a continuation project was not produced because no conceptualization for a tool for facilitating efficient waste logistic was reached within the project scope.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	Knowledge of what is feasible technically, as well as a better understanding for data requirements, was reached.
Be passed on to other advanced technological development projects		

Be passed on to product development projects		
Introduced on the market	X	The position sensors developed by TRAKK, which is a component of a waste transport planning system, will be introduced to the market in Q3 2021.
Used in investigations / regulatory / licensing / political decisions		

8. Conclusions and future research

8.1 Conclusions

The study found that improving the planning of waste transport has potential and it has produced knowledge about the needs for a future waste transport planning system.

One conclusion, supported by many respondents in WP1, is that it would be an advantage to measure filling rate of waste containers. This would enable for waste companies both better transport efficiency and cost savings; along with this reduced CO2 can be expected. An automated solution for estimating the filling rate will be able to relieve the customer from the need of call in/place orders.

Automatic tracking of position in containers is important. This was confirmed by several waste contractors who are actively looking into solutions for container tracking. These have had difficulties in knowing where their containers are, sometimes resulting in failed pickups or picking up the wrong container and there is a confirming need for sensors which can help to locate the containers.

The study of sensors was focused on sensor specifications and limitations and the idea was to analyze what is possible to bring to market with current technology. Measuring weight was here shown to be the most technically difficult parameter to measure. There were problems with the sensors, which were difficult to overcome. With the current available technology, designing a sensor weight system either would be complex with a prohibitive cost or would suffer from problems related to reaching the uptime required by the customers.

The position sensors seem to be a feasible component in a future system. The system currently being developed by TRAKK, based on narrow band low power communication, is planned to become commercially available later in 2021 and has requirements which fulfills the need for cost, roughness and required uptime.

One important lesson learnt is that factors to consider change from customer to customer, even though they do the same activity, which is drivers handling loading and emptying of containers. These factors (see section 6.4 above) have an important role to play for creating a system for efficient waste transport planning. In the design of AI algorithms, they are important to decide for both which data is required, and which optimization to pursuit. These project results are expected to integrate into a decision flow workflow for a logistic waste planning system.

8.2 Future Research

A logical next step is to build further on the knowledge gained from this project and create an effective tool for facilitating efficient planning of waste transport. This would require a conceptualization which would incorporate the following:

- Narrow-band position sensors provided by TRAKK (see WP2).
- Model for assessing the potential savings (see WP4).
- Collection of data and algorithms which capture aspects of actions at customer locations, so the important factors identified (see WP4) are taken into account.
- Method for determining the filling rate of waste containers.

Since a method for automatic determination of filling was not solved in the project, another way to capture this aspect is needed. One option would be manual input for the filling rate (see section 3). This could be done for instance via an app. In addition, to proceed with this plan, a feasible method to capture data at customer locations, details of what is occurring there (loading, unloading, etc.) needs to be created.

9. Participating parties and contact persons

- Thomas Johansson - TRAKK Telematics Solutions AB and CargoSpace24 AB
- Joakim Wigström - Chalmers Industriteknik
- Malin Anderssson - CargoSpace24 AB
- Jens Rangefelt - PreZero Recycling AB
- Henrik Ekvall - BEWI AB
- Thomas Kahlqvist - Ragn-Sells Recycling AB
- Fridolin Jennie - NCC AB
- Mikael Borgman - Renova Miljö AB
- Hans Sahlin - Castellum AB
- Linea Kjellsdotter Ivert - VTI, Statens Väg och Transportforskningsinstitut
- Martin Werdelin - JOAB Försäljnings AB
- Tommy Rosgardt - Volvo Global Trucks AB
- Martin Wåhlin - Cargo Modul Trading AB