IMPLEMENTATION-ORIENTED RECOMMENDATIONS WITH RESPECT TO DYNAMIC WASTE COLLECTION

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TWENTE MILIEU

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Subject:

IMPLEMENTATION-ORIENTED RECOMMENDATIONS WITH RESPECT TO DYNAMIC WASTE COLLECTION

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Executive summary

Current situation:

At the moment, the Twente Milieu N.V. is unsatisfied with the average fill rate of the underground container collection, especially for the residual waste branch. Earlier research has stated that the average fill rate is around 55-57% of the accumulated container capacity. However, it appeared within this research that approximately 63% is utilized in reality. This value is better than earlier assumed, but still far away from an efficient collection process. This also implies that the trucks used to collect the containers have an unnecessarily high mileage and thus produce more CO_2 than desired. Twente Milieu is researching whether there are methodologies in order to reduce the amount of driven kilometres and the number of emptyings of underground containers, while remaining a high service level for customers.

Desired Situation:

It is desired to find a method of container selection and routing that satisfies Twente Milieu's standard to reduce its CO_2-footprint, to save resources and to contribute to a cleaner Twente region. Moreover, a possible cost reduction towards the municipalities is also an issue that has to be taken into consideration weighing the solution alternatives.

Research goal and questions:

The main research goal is to find essential features and issues the Twente Milieu N.V. has to take into consideration, so that a successful implementation of an advanced dynamic routing methodology can be performed, with a minimum lack of knowledge during the actual execution. Therefore, the following research questions were formulated:

1. What are the main failures and drawbacks with regards to the current emptying process of the underground containers?
2. Which data about the underground containers and their collection is available and which conclusions can be drawn from it?
3. What is known about this particular problem of Twente Milieu in the literature and which applications and solution approaches have turned out to be most successful for similar problems?
4. What is the actual usable volume of an underground container that can be filled with refusal?
5. How can the actual amount of waste inside a container be determined in a fairly precise manner?
6. What is the impact of longer workdays – which will be divided into two shifts – on the overall performance of the Twente Milieu N.V.?
7. What are appropriate "learning moments" to determine the actual fill rate of the digital underground containers used by Twente Milieu?
8. What could be improvement suggestions with regards to the information systems and the hardware components Twente Milieu is using for its underground container assortment?
9. Which deeper insights can be gained from the existing simulation model?
10. What is the impact of rescheduling routes during a workday?
11. Which ways of dynamic routing are most promising for the creation of daily collection schedules in an environment the Twente Milieu N.V. is operating in?
12. What are possible effects of direct level sensing of refusal inside underground containers on the overall collection performance?
13. Which saving potential does dynamic routing have in comparison to the current static routing approach used by Twente Milieu?

Main findings:

Non-simulation-related:

- True capacity of a $5m^3$ container is 3,900L, since 22-23% of the $5m^3$ container volume is lost due to pyramid-like accumulation of refusal in the inside (at 90% confidence)
- Dynamic routing cannot be implemented yet. The relationship between the known number of clap openings and the weight of a container is insufficient to determine the waste volume content inside a container. This is due to a high variability in density of the refusal and it is hard to predict the compression factor of the accumulated waste bags within a container.
- To reach a sufficient level of useful data input, an altitude sensor per individual container would be needed in order to determine the waste content precisely enough.
- Water leakages have been detected in several underground containers, especially in Enschede, causing higher maintenance and more expensive deposits at Twence, since the refusal is heavier and it is paid per weight, not per volume. This problem should be tackled soon in order to avoid unnecessary costs.
- The capacity needed for multi-container locations is often exceeding the real demand, thus in various cases too many containers have been placed while a smaller number of containers would also have been sufficient. A demand research ought to be executed in order to assess the real need of a certain capacity of underground containers.
- Multi-container locations show an uneven distribution of waste in the containers placed. In order to increase the profitability of the collection process, the containers should be filled up equally at the collection, so that all of them can be hauled at once without several emptying activities.
- The battery performance of the underground containers appeared to be rather poor and causes higher maintenance efforts. A solution could be to invest in solar-powered container control systems in the future, if the problem seems to extent.
- Communication and information flows at Twente Milieu appeared not to be that smooth in various cases. Data and relevant information is often not available centrally, but has to be acquired through bits and pieces throughout the company.
- The use of two databases for the handling of underground containers is not very efficient according to data mining and control issues. Integration of the Mic-o-Data database into the B-waste database would increase the efficiency of data mining and assessment at Twente Milieu.
- Shifts can be considered useful, since they increase the truck utilization, which means that more containers could be emptied with the use of fewer trucks. The only bottleneck for this is the opening times of Twence. However, a more sophisticated scheduling of the workforce will be needed.
- An alternative routing approach primarily based on zones and secondly on routing might be taken into consideration for the actual implementation of dynamic routing at Twente Milieu.
- A mathematical formula has been developed to determine the precise volume of the waste, based on the altitude of the refusal inside a container alone (see appendix A32).
- RFID applications can be used to decrease data pollution and to avoid manual resetting of the containers. This would also result in a slightly higher working capacity, since the resetting actions can be cancelled out of the daily operations. Furthermore, automated container identification can be realised with relatively low efforts (see appendix A20).

Simulation-related:

- Best dynamic option: **Dynamic Planning (without workload balancing, with fixed number of Must- and May-Go jobs) resp. MayGoFixed.** This is the best performing policy in most of the uncertainty situation, only a sinus variation cannot be handled very well, however, also the results of this policy are only varying 0.2 cost units from the best performing policy under a sinus variation. Thus the winner under the dynamic policies can be seen as Dynamic MayGoFixed. A high May-Go day is performing well (here: 5), since it increases the freedom of choice for the May-Go jobs, from which the best are included in the schedules. The maximum amount of jobs is constraint by the maximum workload. More frequent rescheduling does not that that much impact.
- Must Go day: The Must Go day has to be chosen close to the trade-off between increasing penalties and heavily increasing travel costs. In the scenario simulated for Twente Milieu, the Must Go day should fluctuate around a value of 2 (±0.5 days).
- May Go jobs & May Go day: The addition of MayGo jobs works well in order to reduce the total costs per collected liter refusal. The May Go day should be selected rather large, since in general better system performance can be achieved, if the dynamic routing algorithm can chose relatively freely which jobs can be included and which are not taken into account for an existing route of Must Go jobs that has to be collected anyways. However, there is a drawback connected to this topic, if the MayGo jobs are not constraint by any means, dynamic routing tends to include too many MayGo jobs. Thus, if it is worked with MayGo's, they should be limited in their amount.
- Balancing: The idea of balancing the workload alone generates relatively good results as well. The addition of MayGo jobs, however, deals much better with the workload that the system has to deal with. Therefore, balancing is not included in most of the best policies.
- Combination balancing & May Go jobs: The mix between balancing and the addition of May Go jobs does not function as expected. When both options are included in one policy, the initially positive functionality turns into a drawback. Now overbalancing is happening and the cost saving effects of both methods cancel each other almost completely out. In conclusion, it is not practical to combine balancing with May Go's.
- Rescheduling of a schedule during a workday: Several rescheduling options for dynamic routing have been tested in the various simulation runs for different dynamic policies. The result was always the same; frequent rescheduling throughout a workday, if a part of the truck fleet faces problems, does not improve the cost efficiency of the collection process. Subsequently, rescheduling only the truck that occasionally faces a problem is more than enough to achieve good solution values for the total costs per collected liter refusal.
- *Improvements:* The dynamic MayGoFixed policy has large improvement potential upon the static planning that is pursued at Twente Milieu currently; in particular, the more a system appears to have high uncertainty of one of the three kinds of tested variation used in the simulation (sinus, uniform, standard deviation) in the deposits the more beneficial the dynamic approach becomes.
- *Level sensing:* In general, all the policies worked better under the use of sensor information than without it.
- ***Saving potential of dynamic waste collection:*** **The savings that can be obtained by implementing a dynamic waste collection methodology regarding total costs per collected liter can reach up to +45% in comparison with the currently used methodology.**

Recommendations:

Short-term (before the implementation):

Twente Milieu should look for a level sensing system that can provide enough accuracy for the volume determination within the containers. Ultrasonic sensors appeared to be a decent option in that respect, since they are relatively cheap and fulfil all the requirements needed to measure the altitude of refusal in a container. Moreover, B-waste already started research on this field with the same type of sensor. Therefore, a test ought to be conducted with the sensors in some of the containers of Twente Milieu (see appendix A23).

A volume determination formula that can be found in the appendix A34 can be used in order to calculate the refusal volume within a container. This formula only considers the fill process within a container given certain presumptions that could be retrieved from data given by Twente Milieu or by the conduction several of experiments. To verify the correctness of the formula and the assumptions made, a confirmation experiment should be executed, whether the fill process really behaves as it is expected to be.

Besides that, more research should be carried out upon the variation Twente Milieu is exposed to in its operational environment. This is of utmost importance, since the type of variation decides which dynamic policy fits the best to the company. Also the suspected lost volume of 22-23% in a 5m³ container should be confirmed by an experiment with a real container, since a model has been used in this study. RFID applications to avoid manual resetting and automated container identification can be seen as valuable tools against data pollution and as slightly labour capacity increasing in general.

Long-term (mainly during the implementation and thereafter):

The data retrieval and assessment at Twente Milieu should be made easier, and therefore central information points should be upgraded. Furthermore, the currently used databases (Mic-o-Data and B-waste) should be integrated into one single platform, to simplify analysis of data. The issues connected to the water leakage, battery and other hardware issues should be solved on a mid-term basis. In the long run, Twente Milieu can think about the possibility to introduce shifts on Saturdays as means to enlarge the available labour capacity, especially if the cost pressure increases upon the company these might be useful tools to realize high cost savings.

When dynamic planning is implemented, it should be comparable to the previously described dynamic MayGoFixed policy, since that was the policy that worked optimally for most types of variation.

If it is ought to be decided to equip containers with level sensors, the fill velocity should be investigated to create more accurate forecasts for how long it takes until a container overflows. With regards to this, Twente Milieu should not look for averages in demand, but specifically for the individual containers. In general, Twente Milieu should try to collect more data of the underground containers and on a continuous basis. Only if there is quality and quantity of information input, valuable analysis can be performed successfully. Thus, one ought to strive to use all the means of data collection – that are mostly already present at the company – to open up more improvement potential. This advice mainly concerns data about the weight of the containers at emptying, the number of clap openings on a daily basis and also the altitude of the "waste pyramid" or the hill-like accumulation of refusal inside the underground containers at frequent points in time (preferably every hour, for instance).

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PREFACE

This research project was executed within the context of my bachelor thesis including an internship at the Twente Milieu N.V. in Enschede, from February until April 2011. I am very grateful that I received the chance to participate in a socially important and, additionally, very interesting research on the field of intelligent waste collection principles and methods. It was an utmost inspiring and challenging time I spent at Twente Milieu, helping to generate deeper insights on the possibilities of enhanced efficiency of the collection process of underground containers in the Twente region. Many of the problems I encountered were not straightforward and caused me quite a lot of trouble every once in a while. But at the end, I am convinced that the solutions and recommendation presented in this report are highly valuable for the management of the Twente Milieu N.V. in order to support the decision making process with regards to the underground container project.

I want to thank all the people that have been involved in the cause of this research for their assistance and commitment they showed. In particular, I want to mention my internal supervisors at Twente Milieu, Mr. Gerbert Stegehuis and Mr. Ben Bulters, who perpetually tried their best to provide me with all the information I needed and to make my stay at the company both as comfortable and efficient as possible. Moreover, my supervisor at the University of Twente, Dr. Martijn Mes, was a continuous source of inspiration for me. I highly esteem the creativity and perseverance he revealed during our meetings and that he always gave me well-conceived constructive critique which motivated me to endeavour even more. Of course, also a vast amount of my commitment derived from the very helpful support of my fiancée, Moon-hee, who continuously engaged me to be as active as possible regarding this research. In addition, I would like to thank my parents who have been a great encouragement as well and all my friends that often provided me with very useful and creative ideas. Last, but not least, I want to give thanks to all the workers at the headquarters of Twente Milieu that eagerly tried to support me on the - sometimes rather difficult - quest to find workable data from the wide variety of the internal information streams. Especially, Mr. Arnout Dam was a very big help in this area and should not be left unmentioned.

Thank you everyone!

Sincerely,

Daniel Belter

1 Introduction & research methodology

In this chapter, a general introduction regarding the entire graduation is provided. At first, the focus is directed towards the Twente Milieu N.V. and its unique features. Thereafter, the underground container project is overviewed in general and the reasons for this research, its scope, limitations and expected contributions are examined on. At last, the research structure for this thesis will be explained in more detail to provide the reader with a useful compass throughout this report.

1.1 Twente Milieu N.V.

Type of enterprise

The Twente Milieu N.V. is a government-oriented enterprise which main goal is not profit maximization, but "impact maximization" (Twente Milieu NV, 2010). Thus, the enterprise is focused on offering high societal value for low communal costs. Twente Milieu is a specialist in areas as waste collection, sewer and material maintenance, road ice control, clearance of weeds, emergency services regarding municipal waste issues and pest control.

Short history of the company

The company was founded in 1997 as a result of a merger of municipally owned waste collection and cleaning services of the cities of Enschede, Almelo, Hengelo and Oldenzaal in order minimize bureaucracy and too maximize the efficiency of refusal collection throughout the Twente region.

The municipalities of Hof van Twente and Losser joint this venture in 2001, respectively 2006. Recently, a re-organization took place which led to a division of the Twente Milieu N.V. and the van Gansewinkel B.V., which is in contrary profit-oriented, since it is fully privately owned.

Mission

The long-term mission of Twente Milieu is mainly based on cost reduction for the society and the cleanness and "livableness" of the Twente region that is served. In addition to the previous goal, the preservation of natural resources is one of the main focuses of the company. In general, it is tried to reduce waste wherever possible, encourage citizens to segregate waste and to increase recycling opportunities in various manners. This approach the Twente Milieu is following is summarized in its Dutch motto that describes Twente Milieu as "schoon, gezond, fris" which means that it is indented to be clean, healthy and fresh towards the citizens of the shareholding municipalities. All in all, it is the goal of Twente Milieu to make life with regards to refusal control as pleasant as possible within the Twente area. In the short run, the focus is mainly directed towards an efficient way of collecting all sorts of waste and, of course, a high customer satisfaction.

Vision

Twente Milieu has the vision to become and stay one of the pioneers in effective, fair and societal responsible waste collection processes that benefit the quality of life within the participating municipalities. As for that, especially there is a desire to become one of the first Dutch waste collectors that is actually working with a dynamic routing methodology in order to spare resources of all kinds. In particular, it is aimed to reduce CO_2-footprint of the company as a whole, since it has been shown that CO_2 is one of the most dangerous factors of the current climate change. In this respect, it is prioritized to avoid unnecessarily driven kilometers in the future. Furthermore, it is a big desire of the Twente Milieu N.V. to share the costs for the disposal of waste as fair as possible. Therefore the "Diftar" project was initiated. "Diftar" stands for "geDIFferentieerd TARief" which indicates that residential and corporate container users that produce more waste than others will carry a larger portion of the emerging costs involved. Thus, the ultimate goal is it to encourage citizens to produce fewer refusal with the benefit of saving money in the process.

Key figures

In 2009, Twente Milieu was serving a total population of almost 400,000 inhabitants within the Twente region. The vast majority of them are living in the three bigger cities Enschede, Hengelo and Almelo, which total up to ca. 309,000 people (77%) of the entire collection area (Twente Milieu NV, 2010). At the end of 2009, the Twente Milieu employed 219 employees with an unlimited contract of which about 209 where registered as full-time staff. In addition to the fixed workforce, 36 part-time employees and about 57 temporary workers and ca. 12 detached workers from associated enterprises have been working at the company in 2009.

The total amount of refusal collected is decreasing since 2007 from ca. 225,000,000 kg to 215,000,000 kg in 2009. This reduction of 4.5% is mainly to assign to the impact the financial and economic crises expanding during this time period. Of course, it is one of the goals of Twente Milieu to decrease the amount of refusal that has to be collected as much as possible, however, it is expected that the total tonnage of waste will increase again starting in 2010 due to an improvement of the economic climate of the Dutch corporate environment. In general, the Twente Milieu N.V. is growing every year. The number of attached households grows on average ca. 1.9% per annum. The biggest expansion occurred in 2005 with a percentage of 5.7% more households in comparison to 2004. In recent years, however, the high growth rates appear to be a lot lower than before. In the last three year, for instance, only an average increase of 0.7% was achieved – but still Twente Milieu is expanding.

In 2009, the profit Twente Milieu booked on its accounts was €2,605,000 which yielded an after-tax surplus of €2,123,000. The total equity of the company could be registered with €4,733,000 at the end of 2009.

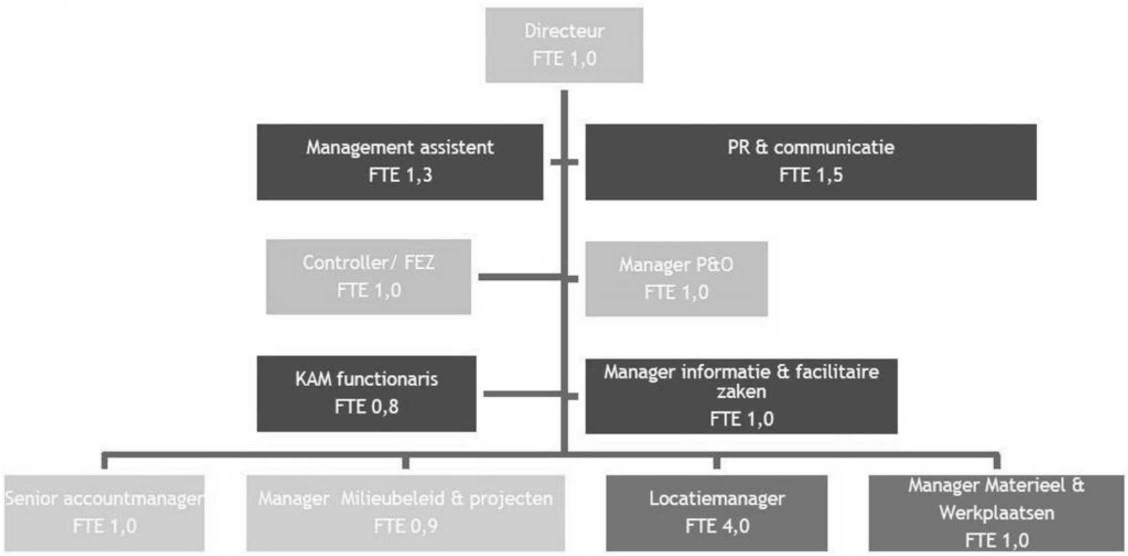
Offered services

The main services which Twente Milieu offers can be split into three main categories:

1. *Waste collection and advice:*
   Under this section the collection of mini-containers (often used at private single houses), block-containers and underground containers for residual solid waste can be placed. In addition, the management of municipal waste collection points, the collection paper, rough refusal, white and brown goods, chemical waste, plastics and illegally placed waste are also part of this. In the advisory field Twente Milieu creates reports about refusal division, container management and policy making of corporate waste handling.
2. *Management of public areas:*
   Pest elimination of harmful animals, as well as street and market cleaning, sludge removal, sewer maintenance, lawn mowing, weed removal is part of this subsection. Furthermore, the Twente Milieu N.V. offers emergency services to municipalities, graffiti removal, support in waste emergency policies and also apartment evictions after foreclosures.
3. *Fleet maintenance and material management:*
   The fleet of Twente Milieu and other municipal service providers need periodically and emergency maintenance which are performed at the company's own repair shop.

Board and managerial structure

The board of Twente Milieu consists out of several members, led by the director Albert van Winden, the board of advisors (three persons), the shareholders and the portfolio holders of the six involved municipalities. The managerial structure can be seen in the staff chart below:



Shareholders

At the moment, the shareholders of the Twente Milieu N.V. are the six municipalities that joint their cleaning and waste collection services up to the year 2007. These municipalities are Enschede, Hengelo, Hof van Twente, Losser and Oldenzaal. From 1997 until 2007, there was a seventh shareholder involved: Essent Milieu. However, its shares were voided in 2007 after the company went through a merger.

Stakeholders

The stakeholders of Twente Milieu are of course its shareholders and the population of the Twente region that is served by the company. Especially in the field of waste collection, pest control and ice elimination the vast majority of the inhabitants of the six shareholding municipalities are affected by the performance of the company. Also tourists might be seen as stakeholders, since they all like to come to a clean Twente. The visibility of the operations of Twente Milieu is rather high and thus it is mostly perceived as value adding to a convenient life style in the Eastern Netherlands.

Collaboration with other enterprises

There are several collaborations with other enterprises that are active in the fields of waste collection and municipal cleansing support. A rather tight collaboration exists with the collectors Berkel Milieu and Circulus that mainly considers knowledge transfer and exchange in the daily areas of operations and strategy issues.

Particularities

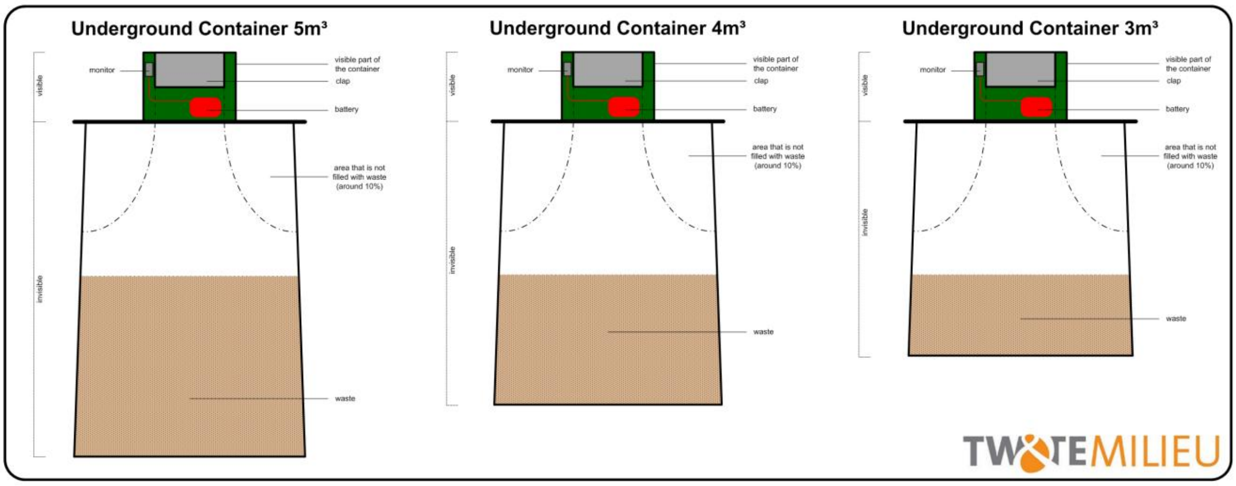
Several years ago, there has been a European tender for an extensive expansion of the underground container project. B-waste, the current supplier, enrolled with the lowest bid and therefore won the tender. Before the underground containers have been delivered by Mic-o-Data; a company similar to B-waste, located in Hengelo. The Twente Milieu N.V. owns the containers of three municipalities completely: Enschede, Hengelo and Hof van Twente. The other three municipalities chose to take their containers into their own possession. Twente Milieu is solely responsible to empty these containers; however maintenance is not part of its tasks, if the containers have an altered ownership status. The biggest drawback of this approach is the maintenance issue, since even urgent repair actions often need administrative approval of the municipal authorities that are involved.

Fleet

At the moment (state: May 2011) the Twente Milieu N.V. possesses four trucks that are capable to collect residual waste in underground containers. However, only two trucks are used for that purpose constantly. The remaining two trucks are only used partially for residual waste collection. They are also operated for glass or paper collection.

1.2 The underground container project

The digital underground container project is one of the most prestigious and ambitious challenges the Twente Milieu N.V faces. Recently, a research study has been conducted that focussed on the feasibility of dynamic waste collection with regards to the underground containers used. It was concluded that a waste collection based on dynamic routing can yield great advantages for Twente Milieu in various ways; for instance a reduction of mileage – implementing less time and gas spent – and a highly flexible and efficient way to react on changes in waste volumes. Especially, the option of balancing the workload and the addition of “May-Go jobs” to existing routes could enhance the performance of the collect operations to a great extent. However, some problems and drawbacks became visible, some of which were mentioned in the preceding research, which can cause some serious concerns with respect to the actual implementation of the proposed new system. I strongly believe that if these observations and warning signals are ignored, the Twente Milieu N.V. might face highly unpleasant surprises when the real implementation of the dynamic waste collection system will take place. Furthermore, the benefits of rescheduling routes during the course of a day are not fully revised yet – which however should be done in order to provide profound recommendations to Twente Milieu that take the true potential the new approach can have into consideration.



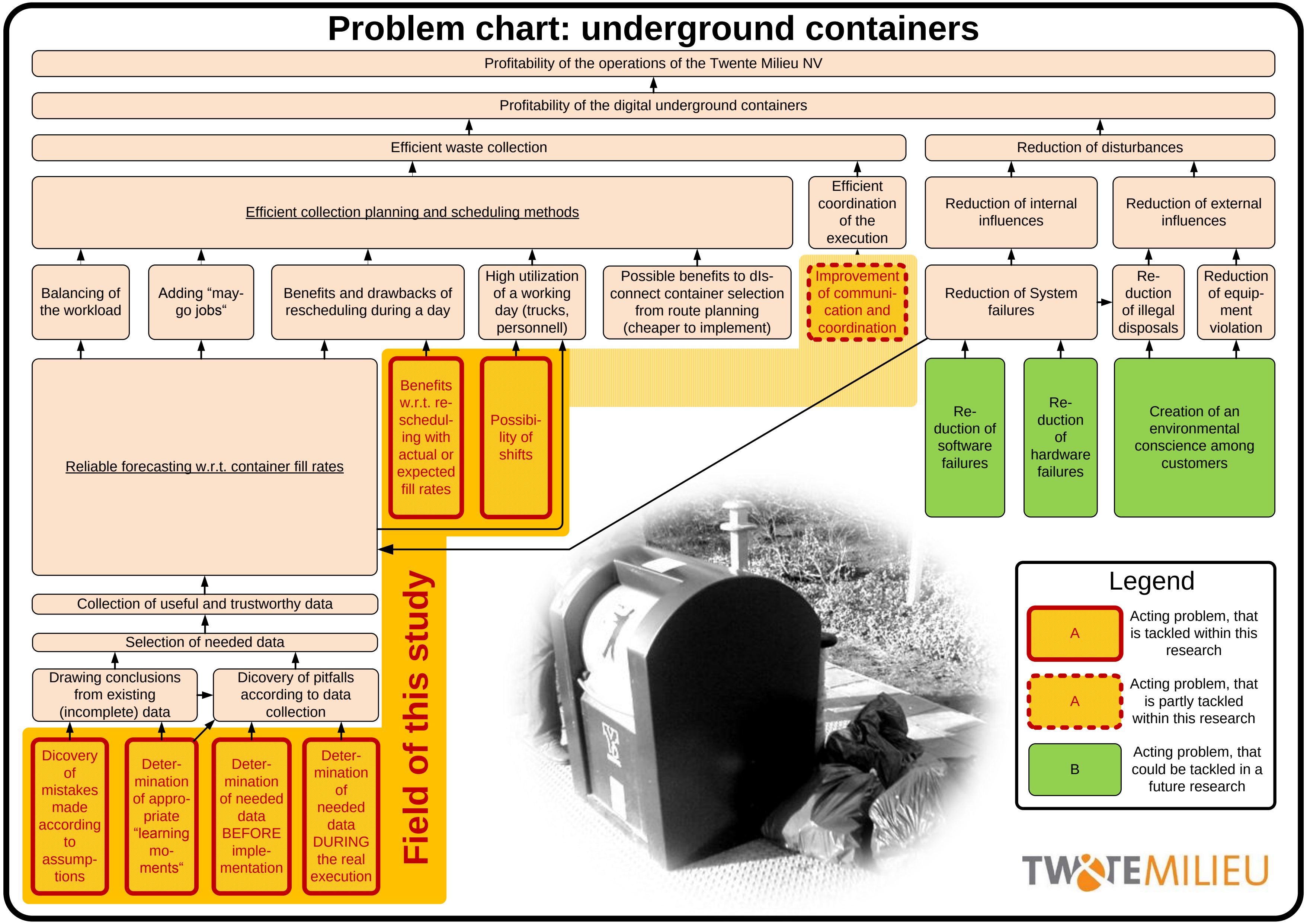
Measures NOT on scale

1.3 Research motivation

The Master graduation research conducted beforehand (Stellingwerff, 2011), mentioned that some inefficiencies can be found in the process of waste collection of underground containers handled by Twente Milieu at the moment. In addition to that, it appears that the basics which are necessary to implement a dynamic waste collection system did not reach the standard required. As can be seen throughout this research, there are some factors that have to be considered to provide the management team of Twente Milieu thorough indications for what it should look for during the soon planned realization. In order to secure the profitability of the underground container project – which contributes in large part to the profitability of the entire organization – it is important to think about efficient methods of waste collection and a reduction of disturbances during the real operations. Regarding the efficiency of the collecting process, the preceding study (Stellingwerff, 2011) already was able to show that, for instance, balancing the workload and the addition of "May-Go" jobs results in a better system performance. However, some potential saving aspects have not been taken into consideration sufficiently yet. Furthermore, the equipment – especially the rather expensive trucks appear to be underutilized, if one takes a look at the Twence B.V., the waste incineration installation, which could handle waste disposals from 7:00 to 19:00, instead of 7:30 to 16:00, as it is common at the moment. Even though the new methods of planning and scheduling are very advanced and seem to yield a better system performance, they are not extremely useful if their input is incorrect. Unfortunately, that is partially the case. The most important input parameter that is necessary to guarantee a smooth working of advanced planning algorithms is the fill rate of individual containers. At the moment, the fill rates appear to be rather far from trustworthy or reliable. To find out why the current measurement approach fails will be one of the key points of my research. Besides, I noticed that the Twente Milieu N.V. at times understates information retrieval from the workforce, which however will only partly be treated during my research.

1.4 Problem chart

A problem chart appeared to be a very nice way to make problems tangible in a visual manner. It does not only show the obvious troubles managers and workers experience during the operational execution of their work, but also it becomes clearer what causes an obvious problem actually can have. In such a chart, one aims to go as deep as possible in the cause and effect chain to finally find a root-cause of a certain hitch. In the case of Twente Milieu, the issues related to a frictionless implementation of a dynamic routing method could be depicted in the next chart. Basically, problems that are easily visible in the daily work are ordered up higher, while the causes of a certain problem can be found in lower levels of the graphical hierarchy. It has been indented to make the chart as complete as possible, however there also might be other causes of a problem that could not been taken into account, for instance due to incomplete information. Thus, it is crucial for Twente Milieu to not take the chart below as absolute, but always it should be tried to find additional trouble-causing elements if one suspects them to be of value for a successful solution – in this case the frictionless implementation of dynamic waste collection.


Problem chart: underground containers
Profitability of the operations of the Twente Milieu NV
Profitability of the digital underground containers
Efficient waste collection
Reduction of disturbances
Efficient collection planning and scheduling methods
Efficient coordination of the execution
Reduction of internal influences
Reduction of external influences
Balancing of the workload
Adding "may-go jobs"
Benefits and drawbacks of rescheduling during a day
High utilization of a working day (trucks, personnell)
Possible benefits to dis-connect container selection from route planning (cheaper to implement)
Improvement of communi-cation and coordination
Reduction of System failures
Re-duction of illegal disposals
Reduction of equip-ment violation
Reliable forecasting w.r.t. container fill rates
Benefits w.r.t. re-schedul-ing with actual or expected fill rates
Possibi-lity of shifts
Re-duction of software failures
Re-duction of hardware failures
Creation of an environmental conscience among customers
Field of this study
Collection of useful and trustworthy data
Selection of needed data
Drawing conclusions from existing (incomplete) data
Dicovery of pitfalls according to data collection
Dicovery of mistakes made according to assump-tions
Deter-mination of appro-priate "learning mo-ments"
Deter-mination of needed data BEFORE imple-mentation
Deter-mination of needed data DURING the real execution
Legend
A
Acting problem, that is tackled within this research
A
Acting problem, that is partly tackled within this research
B
Acting problem, that could be tackled in a future research
TWENTEMILIEU

1.6 Research questions and goals

Derived from the problem chart, I formulated the following research (sub-) questions below to specify my focus according to the problems connected to the digital underground containers:

Main research goal:

Which essential features and issues should the Twente Milieu N.V. take into consideration, so that a successful implementation of an advanced dynamic routing methodology can be performed, with a minimum lack of knowledge during the actual execution?

Referring to the main research goal, the following sub-questions were formulated:

- *What are the main failures and drawbacks with regards to the current emptying process of the underground containers?*
  - This issue will be studied by conducting interviews among the operational workforce and a thorough data analysis
- *Which data about the underground containers and their collection is available and which conclusions can be drawn from it?*
- *What is known about this particular case of Twente Milieu in the literature and which applications and solution approaches have turned out to be most successful for similar problems?*
  - A literature study will be carried out in order to detect similar problems that are adaptable for the case scenario of Twente Milieu and to find useful solution approaches that have been examined in the past.
- *What is the actual usable volume of an underground container that can be filled with refusal?*
  - This problem will be researched with a container model simulation. The main goal is to see how much of the initial volume of an underground container is lost due to the fill behaviour caused by solid waste units.
- *How can the actual amount of waste inside a container be determined in a fairly precise manner?*
  - Based on assumptions gained from the previous research question, it is indented to create a waste volume determination formula that is able to describe the actual volume of refusal within a container as accurate is possible.
- *What is the impact of longer workdays – which would be divided into two shifts – on the overall performance of the Twente Milieu N.V.?*
  - This will be done by adapting the simulation model compiled by my predecessor.
- *What are appropriate "learning moments" to determine the actual fill rate of the digital underground containers used by Twente Milieu?*
  - For this purpose historical data will be assessed and other methods of information collection will be used (e.g. brainstorm sessions and interviews, field trips). Learning moments represent decision points in time, which might alter the direction of a followed approach based on the information that has been gained until or after a certain time period.
- *What could be improvement suggestions with regards to the information systems and the hardware components Twente Milieu is using for its underground container assortment?*
- *Which deeper insights can be gained from the existing simulation model?*
- *What is the impact of rescheduling routes during a workday?*
  - For the last two points a revision of the prepared simulation model will take place and necessary adaptations will be performed.

- *Which ways of dynamic routing are most promising for the creation of daily collection schedules in an environment the Twente Milieu N.V. is operating in?*
  - Since there are several options in dynamically planning the collection of underground containers that are simulated, it is tried to figure out the best fit for Twente Milieu and its operational environment.
- *What are possible effects of direct level sensing of refusal inside underground containers on the overall collection performance?*
  - Again the simulation study described in later chapters will help to gain more knowledge on this topic.
- *Which saving potential does dynamic routing have in comparison to the current static routing approach used by Twente Milieu?*
  - At the end of this research the overall performance of the current and a potentially beneficial dynamic planning approach will be benchmarked against each other.

The main goal of my research is to give decision support to the management of Twente Milieu with regards to the pitfalls and opportunities of the upcoming implementation of a new advanced planning system. Even if not all the required data can be sought out in detail, the indications on what to focus on, given in this research, will make it easier for the responsible managers at Twente Milieu not to forget to look in certain directions before the actual adoption of the new system. Moreover, there is a realistic possibility to make the new planning methods even more beneficial for the Twente Milieu N.V in financial terms. This opportunity should definitely not be missed out.

Research approach

The research subjects will be approached in several manners. At first, data mining and analysis from existing databases will be carried out, which is one of the central parts of this study. It appears that the number of clap openings alone might not be the best way to predict the true container content and in practice a lot of variation in accuracy of a container fill is observable. To go to the bottom of the previously mentioned issue, is a highly important step within this research. At the moment, Twente Milieu handles two different databases with regards to the underground containers in use – namely Mic-o-data and B-waste. The quality and quantity of the data deviates in several cases to a quite perceptible extend, which gave me the hint to collect more information via a number of other important channels. As for that, in particular interviews with employees and managers involved will be used and besides a brainstorm session concerning the subject is held as well. With regards to the simulation model, my university supervisor and I are going to adapt the existing model from Stellingwerff's study in order to fulfil to the research questions about several dynamic planning options mentioned in the previous section. At the end, with the output data from the simulation, a sensitivity analysis will be performed to provide a profound decision support to the Twente Milieu N.V. and to show the potential savings that can be obtained by an implementation of a dynamic routing methodology for solid waste collection.

Besides, the focus is directed towards non-computational topics, as already mentioned in the other sub questions of the research goal. Mainly, the exploration of the fill behaviour of a container and its true volume capacity will be essential in later parts of this study. To conduct usable results with regards to these points, for example, a paper model simulation of a 5m³ container will be set into the focus, as well as a mathematical approach to derive a helpful formula that can describe the fill process of an underground container in a rather accurate manner.

1.7 Scope of the project

The project on recommendations of the implementation of a dynamic container collection methodology is heavily based on the master graduation project "Dynamic waste collection" carried out by Stellingwerff in 2011. Thus the vast majority of the used simulation model was already coded and just needs some adaption to circumstances that altered during the course of the internship execution at the Twente milieu N.V. The main focus is directed towards practical advices that the management of Twente Milieu ought to take into consideration to avoid pitfalls the underground container project involves. Especially, for research purposes, the existing simulation model, hardware and software components of the containers used and partially the communication structure at Twente Milieu will be examined in further detail. A very essential issue are the learning moments with respect to the data that is currently available and to the data that might be acquired additionally in order to assure that the full potential is used that can be gained by the underground containers in combination with dynamic routing. These moments mainly describe a change in handling specific data and the results that arise and how to analyse them thoroughly. Thus, in this research it will be investigated if there exist certain repetitive information flows that can help to gain deeper understanding of, for example, similarities of fill patterns in different collection neighbourhoods and their individual properties. This means that, if sufficient data about a particular issue is collected in the future, the assumptions used might change according to the data – if it is considered to be valid for the process.

1.8 Limitations

In the problem chart can be read that this study mainly focuses on several issues related to planning methods and the analysis of existing data regarding fill rates of individual containers. Other areas that might also have a substantial impact on the smoothness of implementation of the new system will not be considered. To this category belong the creation of an environmental conscience among the customers, a reduction of hardware failures and a reduction of software failures. Latter is of outmost importance for a real implementation, but unfortunately the timeframe of this study – which is ought to be ten weeks – does not allow me to dive into that field of interest too much. In addition, the coordination and communication structure with respect to the responsibilities of the underground containers will only be touch slightly, but the most significant observations and conclusions will also appear in the report of this study.

1.9 Expected contributions and results

With the research conducted within the above mentioned framework, the Twente Milieu N.V. will be able benefit in many ways. First of all, guidelines towards the actual implementation of a dynamic waste collection system will be clearer for the managers involved. They will know on what to focus on and which questions to ask to an executing consulting firm in order to ensure a smooth conversion from the current to the new planning system. Additionally, mistakes that have been underestimated in the past can be taken into account in the corporate learning process which will help the management team to prevent the same errors from happening again in the future. Furthermore, the anticipated positive impacts of rescheduling routes during a working day, shift operations and several dynamic approaches will be examined which can enable the Twente Milieu N.V. to realize even more savings than already assumed.

1.10 Research execution

Within the framework of my internship at the Twente Milieu N.V., I performed a wide variety of tasks and activities that can be reviewed in appendix A9.
Mainly, the activities that have been and will be performed can be divided into the following subcategories:

- *Interviewing employees:* The interviews are conducted in particular from employees that have operational insights with digital underground containers on a daily basis. In appendix A5 these interviews are summarized.
- *Data mining and correction:* In order to get useful data that can be exploited for the solution alternatives, weight sample measurements will be taken and further data about the clap opening frequencies will be generated by digging into the two used databases of B-waste and Mic-o-Data.
- *Literature research:* The goal of the literature research is to create a framework that enables the reader to position this thesis in a scientific context. Furthermore, articles will be reviewed to retrieve useful information on scientific approaches that can be adapted or even were very similar to the case description of Twente Milieu.
- *Meetings with UT-supervisor:* To keep track of the progress in the simulation and to discuss various points of interest and doubt within this research, I asked advice from my supervisor at the University of Twente for several times. He helped me to develop a wider view on the problem and to find a direction in the fields of data mining and critical review of the processes that take place at the Twente Milieu N.V.
- *Meetings with Twente-Milieu-supervisor(s):* This type of meetings is mostly very insightful, since a direct view on the actions and procedures at Twente Milieu could be examined. Also they were intended to give my company-internal supervisors a heads-up on new discoveries and developments within the framework of my internship.

- *Field trips with waste collectors:* In order to get a realistic view on the operations that are executed during the collection of underground containers, it seems handy to do a field trip with a waste collector and his or her vehicle. Many things might differ in realty as they were supposed to be in theory. Additionally, my colleague Arnout Dam does some field trips by himself as well; therefore we will be able to commonly collect a lot of useful data that can be applied to open up more knowledge about the collection of the underground containers and the difficulties connected to it.
- *Visits at supplier:* I will have the chance to participate in several visits to Twente Milieu's supplier B-waste. A meeting with the previous supplier Mic-o-data unfortunately was cancelled due to discrepancies according the timing of a visit. The company tour and the subsequent question and answer sessions were very helpful to understand the points of view of the supplier and how their products – the underground containers und the supporting databases – could be improved in their performance. Several ideas popped up – under which also the level sensing with ultrasonic sensors or an adaption of the display modules – which also showed some difficulties in practice.
- *Organization of a brainstorm session:* Another opportunity was given to me to organize a brainstorm session after some weeks of the research project to order the knowledge and information streams within Twente Milieu that were related with the underground container project. Afterwards it is to say that this session was of outmost importance for me to get a better understanding of the ongoing troubles with the containers and the potential they are bearing with them. The presentation of the brainstorm session can be reviewed in the end of this report in appendix A4.
- *Contacting potential sensor suppliers:* After figuring out that it might be more practical to use a level sensor instead of the number of clap openings alone to predict the volume of waste inside a container, I will contact a bunch of possible sensor suppliers to get more information about level sensing in general and also about the price that would be attached to alterations of the existing set of containers.
- *Simulation modeling:* The vast majority of this part of my research is conducted by my supervisor at the University of Twente. My role mostly was advisory and at times I will perform some small adaptations to the existing code in order to help with the debugging of the model or to fulfill smaller coding projects. All in all, the simulation will take a lot of time and not all of the possible experimental factors might be examined into their last detail. However, the most important facts will be observable, even with a restricted set of factor.
- *Simulation data analysis and model verification:* One of my main tasks at the Twente milieu N.V. is to collect sufficient and trustworthy data in order to help my university supervisor to create a model as close to reality as possible. Therefore a lot of data analysis and reality checks will to be performed to ensure the verification and validation of the model.
- *Designing a zone-based dynamic selection and routing algorithm:* In order to give an addition to the already proposed methods and algorithms of Stellingwerff, another container selection method is thought of in the course of this bachelor project. It is mainly based on the cluster first route second algorithm, a method that is already well known in the literature. However, the method proposed in this report involves some noticeable deviations.
- *Designing a waste volume determination formula for a 5m^3 container:* Since Twente Milieu does not fully have insights on the actual volume that is able to be stored in its container assortment, a model-based simulation study is carried out to gather more knowledge on how a container fills and how much of its original volume is lost due to the pyramid-like filling process. Thereafter a formula predicting the volume within in a container is constructed (appendix A8, A28).
- *Thesis transcription and reflection:* The internship at the Twente Milieu N.V. is formalized in this report. Partially this happens at the company's facilities themselves and also in addition at the UT. It is indented to give the reader of this document a clearer image to understand the difficulties connected to the implementation of an advanced planning and routing methodology and which solution might be considered to solve these difficulties. Furthermore, a reflection of my internship can be found at the end of this report.
- *Presentation preparation:* After the report is completed as some time will be spent on the preparation of a presentation of the findings and recommendations related to the study that has been carried out. This might be done after the formal period of the internship at the Twente Milieu N.V. has ended.

1.11 Thesis setup

This section elaborates on the organization of this thesis report, executed on the behalf of the Twente Milieu N.V. and the particularities connected to it.

At the beginning, it is started with an executive summary. The goal of this is to provide the Management of Twente Milieu with a short summary of the results, conclusions and recommendations conducted within the framework of my internship at the company. A Dutch version was intended to be very straight forward and short, while the English one is a little bit longer in order to give a little more insights than the pure outcomes; however due to size restriction the Dutch version has been cut out. Thereafter, different tables of navigation are given to simplify the orientation within the thesis framework. A table of contents, illustrations and appendices are included. A preface follows up on that section as well as a list of definitions and abbreviations used throughout the report.

Chapter 1 provides a general introduction to the Twente Milieu N.V. and its particularities. Moreover, things like specifics of the underground container project, the research motivation, questions and goals, scope, limitations and expected contributions of the thesis are examined. Also a short summary about the activities done at the company and its suppliers and a thorough explanation about the research set-up is presented.

Chapter 2 mainly focuses on the current situation of Twente Milieu with respect to the underground container project. Topics like current method of emptying and scheduling, truck utilization and general features of the underground containers are discussed. Special attention is directed towards several apparent problems and current assumptions used.

In the third chapter, the desired situation that Twente Milieu is eager to achieve is elaborated on. In a vast extent the requirements and constraints for a successful implementation of a dynamic routing approach are reviewed. The main goal of this chapter is to provide a goal that should be reached within a certain set of conditions.

Knowing the desired situation a data analysis is performed in chapter 4 in order to search for data that can be helpful to reach the goals previously defined. Therefore, sample measurements, and in particular disposal-related data will be examined to give valid input for the simulation model and other non-computational solutions.

A literature study is carried out in the fifth chapter of this report. This review is aimed to give a clear up picture about the research topic itself. The goal is here to give the reader a better idea in which field of science this thesis can be positioned and what kind of studies already have been conducted that might also be influential for this thesis. Within this research it is looked at literature with relations to the inventory routing problem and issues of dynamic routing within the field of solid waste management of municipalities.

Since this thesis is partially based on a simulation study – which mainly has be executed by Stellingwerff and Mes – the sixth chapter considers the general set-up of the simulation model used and adaptations that have been made to it in comparison to older versions of the model.

By the means of data mining (chapter 4), recommendations and conclusions of previous studies (chapter 5) and the use of a simulation model (described in chapter 6) , it is intended to create several solution alternatives that are able to tackle the problems that became apparent in the chapters 1 and 2. Chapter 7 fulfills this purpose and divided the conducted results into computational and non-computational ones.

The results presented in chapter 7 are furthermore summarized and conclusions from them will be drawn in chapter 8, in addition to other conclusions that also become important throughout earlier chapters of the report. These conclusions are the used in chapter 9 in order to give useful, appropriate and insight creating recommendations to the management team of Twente Milieu. This chapter also includes a section with personal remarks that ought to be considered as an addition to the "harder" recommendations of the preceding section.

Chapter 10 explains the scientific and societal contribution of this thesis, while chapter 11 gives further suggestions on research that might be executed based on the outcomes of this study.

The official part of the report finishes with the evaluation and reflection of the experienced internship at Twente Milieu in chapter 12.

2 Current Situation

In this chapter, the current situation at the Twente Milieu N.V. will be described with the focus on the underground containers used at the moment. At first a general perception of the project and the company itself will be examined which will mainly take advantages and disadvantages of the containers and currently used performance measurements and assumptions into account. Furthermore, it will be looked at the emptying methodologies executed at Twente Milieu and their impact on scheduling and routing of the crane-equipped truck fleet. The utilization of the truck fleet and general data features of underground containers are other issues that will be treated in this chapter. Thereafter, a variety of troubles and pit-falls will be discussed that are related to the underground containers. At the end, a brief local conclusion section will summarize all the findings connected to the current situation at Twente Milieu.

In the appendix A12 a picture is showing the current types of underground containers used by the Twente Milieu N.V. Special attention is to put on section picture number 2, since it clearly emphasizes the difference between a 3 and 5m^3. Most of the issues addressed in this or later chapters, however, are mainly focusing on the 5m^3 container, due to the fact that at the moment it is the most frequently used one.

Furthermore, the feed chute or lid is visible in the section pictures 1 and 5 mainly constraining the size of the waste bags that can be deposited. Picture 3 showing the maintenance door on the left-hand side of the container (seen from the lid). This opening might become interesting for adaptations in hardware of the current design (see later chapters).

2.1 Daily operations with the underground containers

At the moment, Twente Milieu has already applied a large number of underground containers can be seen in the table below:

Container locations & # of containers

date: 24.03.2011

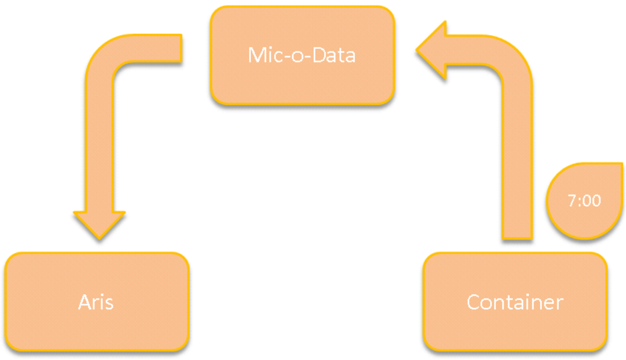
		# Locations	# Containers	#1 per location	#2 per location	#3 per location	#4 per location	#5 per location	# of containers per location	Total
Enschede	Bwaste	182	226	143	34	5			1,242	226
Enschede	Micodata	92	134	59	26	6		1	1,457	134
Enschede	**Total**	**274**	**360**	**202**	**60**	**11**	**0**	**1**	**1,314**	**360**
Hengelo	Bwaste	195	229	167	22	6			1,174	229
Hengelo	Micodata	4	5	3	1				1,25	5
Hengelo	**Total**	**199**	**234**	**170**	**23**	**6**	**0**	**0**	**1,176**	**234**
Almelo	Bwaste	43	49	37	6				1,14	49
Almelo	Micodata									0
Almelo	**Total**	**43**	**49**	**37**	**6**	**0**	**0**	**0**	**1,14**	**49**
Oldenzaal	Bwaste	14	15	13	1				1,071	15
Oldenzaal	Micodata									0
Oldenzaal	**Total**	**14**	**15**	**13**	**1**	**0**	**0**	**0**	**1,071**	**15**
Hof van Twente	Bwaste	9	11	7	2				1,222	11
Hof van Twente	Micodata	5	5	5					1	5
Hof van Twente	**Total**	**14**	**16**	**12**	**2**	**0**	**0**	**0**	**1,143**	**16**
Losser	Bwaste	3	3	3					1	3
Losser	Micodata									0
Losser	**Total**	**3**	**3**	**3**	**0**	**0**	**0**	**0**	**1**	**3**
Total	Bwaste	446	533	370	65	11	0	0	1,195	533
Total	Micodata	101	144	67	27	6	0	1	1,426	144
Total	**Total**	**547**	**677**	**437**	**92**	**17**	**0**	**1**	**1,238**	**677**

Most of the underground containers are placed in the municipalities of Enschede and Hengelo with each more than approximately 200 containers. Almelo, Oldenzaal, Hof van Twente and especially Losser have much less digital underground containers yet, but this is about to change in the near future. There are two reasons for this: first of all, it is intended to re-adjust the old non-digital versions of containers in Almelo with new digital one and furthermore more and more block containers are vanishing out of the city landscape of all the municipalities. In particular in Hengelo, the increase of digital underground container locations is very high.

Most of the container locations (Dutch: zuilen) have one container per location; however, there are also a lot of locations, that have two or more containers at one spot. This becomes very visible in dense municipalities that have more of an urban than a rural infrastructure. Due to that Enschede has the highest rate of containers per location, while in more spread out regions, like Oldenzaal, Losser or Hof van Twente this effect appears to be less observable. In the table to the left Almelo also has a low container per location ratio; the main cause for that is most likely the fact that many of the containers are not digital yet and thus do not count.

Advantages of used underground containers

The underground containers and the collection fleet applied at the moment have several advantages that are partially used, however also some features are not fully exploited yet. The biggest advantage is that with the containers count the number of clap openings, that enabled Twente Milieu to retrieve deeper insights into the speed of the container fill process. This feature also was the reason to conduct this research and the one of Stellingwerff beforehand. The data transfer of the amount of clap openings works as described in the figure to the left: Once a day at, normally around 7:00 in the morning the status on the amount of clap openings from the previous day is updated. The information then is transferred to Mic-o-Data (the initial container supplier) or B-waste (the current supplier). After a short failure review at these companies the data is sent to the “Aris”, a software package used at the Twente Milieu N.V. to access the openings data. The fact that new insights on the container fill could be generated by relatively low efforts appeared to have a very useful impact on the planning and scheduling of the container collection – which however was not fully true as elaborated in later chapters. Furthermore, the containers are equipped with a digital lock that only can be opened by a participant-owned RFID-card. DifTar, that has been described earlier, can be introduced based on this feature, which might have a large impact of the environmental awareness of the container users.



Performance measurement at Twente Milieu

The performance that the Twente Milieu N.V. is measuring is mainly based on customer satisfaction, utilization of the containers and utilization of the collection fleet. These three key issues will also be later on discussed for the KPI (Key Performance Indicator) of the simulation study that is carried out. The most important short term measurement is the number of complaints of the residents of the Twente region. If they are unsatisfied with the performance delivered by the Twente Milieu N.V. it is a clear alarm signal for all parties involved. However, also more and more the carbon footprint receives increasing attention from the management of Twente Milieu, which is mainly connected to the mileage of the truck fleet. Looking a level deeper, the mentioned mileage can only be reduced if especially the utilization of the underground containers can be increased to an adequate percentage. As goal a value around 80+ % of the average containers fill is intended. In order to keep customer satisfaction high enough, the number of late emptying ought not to be larger than 3 out of 100 containers on the long term. As already indicated by Stellingwerff these goals are far from being reached yet, therefore there is still some space for improvement obtainable.

2.2 Method of emptying underground containers

At the moment, routing and scheduling of containers is done on a static and cyclic basis with some deviations in the routes incorporated. The static planning normally considers weekly emptying of most of the containers that Twente Milieu serves. However, there are also containers that have longer emptying periods of, for instance, two or more weeks – but these are just a minority. The deviations that are included in the schedule of collection are due to the drivers’ freedom to pick up more containers (or also less) based on this experience. This means that containers are basically never really emptied according their scheduled times. A driver makes a decision for the may-go containers and the ones that are eliminated from the schedule for a particular week. All in all it can be said that the collection process is rather based on personal perception and experience rather than on an actual schedule that is carried out as supposed. In addition, trucks are always cleared before the evening hours, meaning that almost every workday there is a visit at Twence around 15:00-16:00.

Further information on the collection procedure can be reviewed in Stellingswerff’s study (2011) in chapter 2.

2.3 Truck utilization

Spoken about performance features, it is quite essential to define performance, respectively utilization, in advance. In this report, the truck utilization standard is measured against the possible longest workable time the fleet might be used during a week. In the case of Twente Milieu, the operations can be measured against the working hours of the Twente Milieu N.V. itself as well as the opening times of the Twence B.V. (which however is not the constraining factor of the operations at the moment). Since this study aims for improvement and the tackling of hidden potential, it is decided to measure the truck utilization against the Twence B.V. as a possible bottleneck of the operations of Twente Milieu.

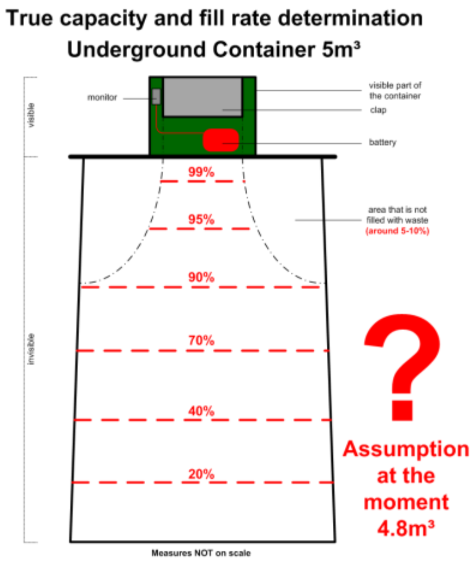
Seen the definition proposed above, the fleet is only used for 8/12=66.7% of the possible time that might be used for any operation. This value emerges if it is taken into consideration, that the Twence B.V. can receive refusal deposits for 12 hours a day – while Twente Milieu is currently depositing for only 8 hours during one day. Besides, taking the price of a purchase of a new truck (€ 300,000) in a situation of capacity shortcomings into account, this utilization ought to be increased. Especially this should be done, if capacity constraints and higher investments fall into the same time frame.

2.4 General problems with refusal containers

In this section of the report general problems that are connected to the non-operable fill rate and capacity determination are focussed on. Also, hardware issues and troubles with the data management of the containers are examined.

2.4.1 Problems with fill rate determination

Up till now it seems that no good method has been found yet to determine the actual amount of refusal that has been stored in one of the containers of Twente Milieu. At the beginning of the introduction of the clap-opening-based fill rate determination method a lot of hopes where present to get more insights on the real fill volume of the containers with relatively low efforts involved, however these hopes appear to stay unfulfilled, since the tolerance of the determination of volume is apparently too high to base an fill-rate-driven routing approach on it. Therefore, the routing due to the fill rate was abolished relatively fast after its initial implementation. One was rather disappointed about the results and returned to the experience-based static method, which works quite well with focus on the customer satisfaction regarding late pick up refusal. On the other hand, it is still believed that dynamic routing can improve the performance of the Twente Milieu N.V. especially seen a reduction of CO_2, that is emitted by its fleet.



Uncertainty about container capacity

At the moment Twente Milieu handles the assumption that 10% of the total container volume (e.g. 5, 4 or 3 m³) is lost due to a pyramid-like fill process of the solid waste deposited into the containers. The figure on the left describes this assumption. The upper corners cannot be filled with waste – that appears to be obvious. However, what is not obvious is the exact amount of volume that is lost in these areas. Currently, the filling procedure has not been examined yet and thus there is a strong doubt from my side, whether a loss of 10% might be accurate enough to determine the true amount of lost volume in a container. Furthermore, it seems not clear at which height of the waste a certain volume has been reached. Therefore, a deeper examination of this issue will be addressed in later chapters of this report.

Uncertainty about density of waste of individual containers

It is supposed at the moment that the density of waste stored in a container is almost always the same for every container with a density of 0.1 kg per liter. However, also seen the data analysis is assumption might be not correct for all the containers, since it is just an average. It appears that the standard deviation of this value is rather big, seen the sample measurements in the following chapter. So far a clear knowledge about the waste density is not present for each of the individual containers – this however is necessary to determine the waste volume solely based on weight of a container and the number of clap openings.

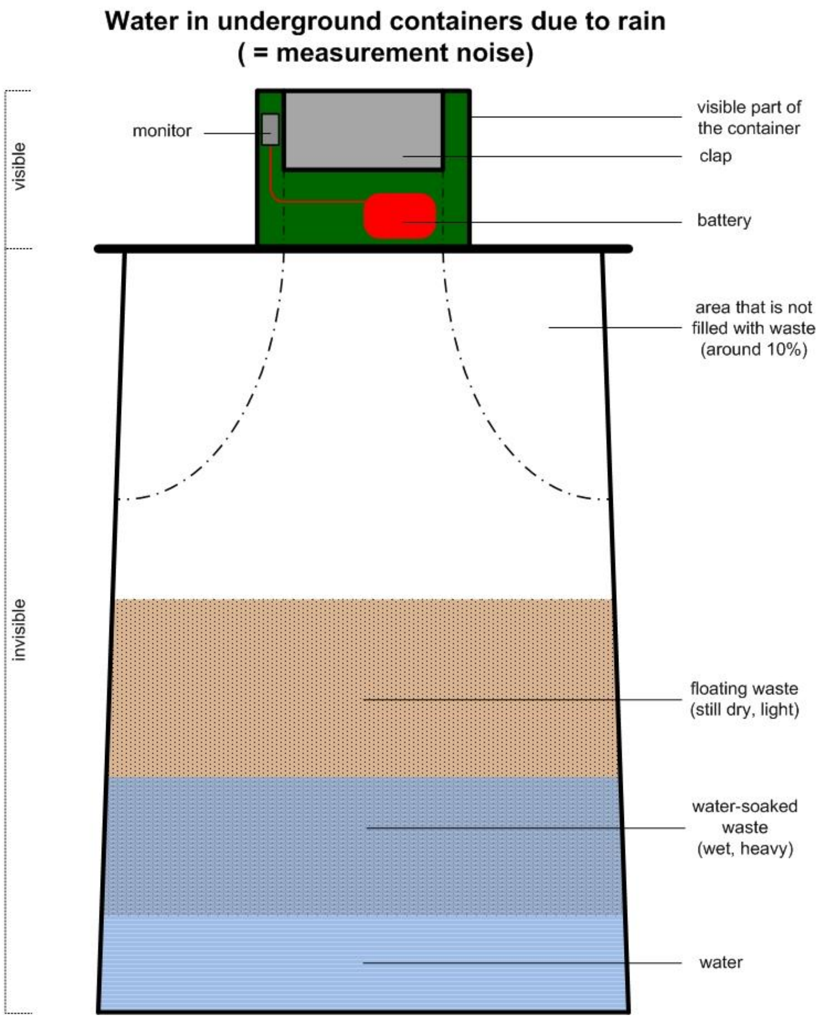
Determination of needed capacity at several multi-container locations

Multi-container locations show difficulties that might cause problems with the implementation of a dynamic routing approach; first of all the waste in the containers appears to be unevenly spread, which is very unfavourable for an cost reduction in hauling, since it is, of course, much more cost efficient to collect two or more full containers at once than driving to a certain location again and again in order to empty each container individually when it runs full. Data evidence of this issue can be found in the chapter "Data Analysis".

2.4.2 Hardware disturbances

Water leakages

There are several underground containers that the Twente Milieu possesses that relatively frequent seem to have troubles with water accumulations in the pits of a container. Referring to the interview with an employee working on maintenance (see appendix A5) these kinds of problems have a higher frequency to occur in Enschede than in other shareholding municipalities. This problem is important to solve for the following reasons:



First of all, the water in the pits causes a vast amount of material deterioration that will be examined later on. Secondly, but actually most important, the refusal deposited into the container becomes all watery and in bad cases floats on the layer of water. Since, deposits at Twence are paid in kilograms, that wet waste is a lot more expensive for Twente Milieu and its participating municipalities than dry waste. Furthermore, when the refusal stays wet for a longer period of time – which might be the case in a dynamic routing scenario, bacteria could develop rather easily, which might cause health issues. Also, if residents throw away chemical waste into a residual waste container – even though that is illegal, but it might happen – toxic components of that refusal might then accidently seep down into the soil underneath the pit of a container. Later on they might end up in the ground water; and in that case it can cause an even severe health issue in the long run. The figure within this section depictures the situation of such a container that has a water leakage problem. As can be seen, the accumulation of water at the bottom can also be responsible for noise in the volume measurement while weighing the containers. Also if a sensor application would be used in the future, this can cause trouble if the situation does not improve.

Battery performance

The battery performance of the containers seems to be not that over-whelming. When interviewing maintenance (appendix A5) it also came to attention that the batteries used in the containers have insufficient capacity and run out of power faster than generally expected. A battery has an initial voltage of 18 Volt and is supposed to be changed at a voltage of 4.5 Volt. According to the supplier a battery is ought to last for about two years in service. In reality this horizon is however often not met and batteries have to be exchanged earlier than their intended due dates. Also with the view on a possible level sensing this issue should get some attention, since a stable power supply is essential for a good and continuous performance in collection.

Material deterioration

Deterioration in material was one of the issues that emerged during an interview with a maintenance employee (see appendix A5) and even during the field trip that has been made; drivers appeared to have the same opinion about that fact (see appendix A5). Especially, the thickness of the material of the new B-waste containers was viewed with criticism, since the wear is apparently larger than with the old Mic-o-Data containers that used relatively thick steel sheets in their fabrication. Mainly, the wear of the upper gripper handle on top of the containers seemed to be the problem. When a container is pulled out of the ground, the driver uses the gripper arm in order to impose it on the gripper handle at the container and pulls it up to the truck disposal unit. However, when a container is pulled out of the ground in a tilted way, the material deteriorates faster at certain spots. Apparently, this mostly the case with containers that are positioned close to buildings or areas those are difficult to reach for the collectors (see appendix A5). Besides the wear also corrosion, plays a role, seemingly several containers already have signs of corrosion after a short period of time in use. This partially is also caused by the water leakages that were explained in an earlier section of this chapter.

Vandalism

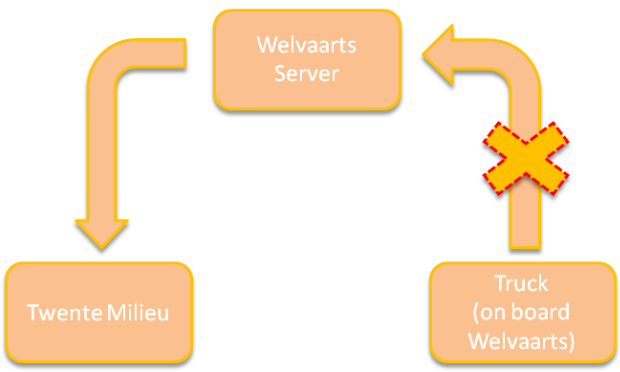
According to vandalism, there is to say that mainly varies from region to region where containers are in use. In most of the area the Twente Milieu is active, no severe occurrences of that kind take place; however, in several neighbourhoods it appears to be common that containers are demolished, sprayed or maliciously modified. As it seems, the activator button placed next to the lid of the containers is the item of a container that is vandalized the most (Interview maintenance employee, appendix A5). Moreover, graffiti's and demolition of the display, the lid and the maintenance door are ranked in that order after the violations on the buttons.

Display issues

In addition to the previously mentioned problems with vandalism, that also concerned the displays of the underground containers, unfortunately there are more issues connected to that technological feature. Again water and condensation troubles appear to be the biggest obstacle in this respect (see appendix A5). When displays condensates due to water invasion of its housing the data displayed on the small monitor is not readable anymore for the user. Due to this fact, it is for instance often not possible to see with the blank eye whether a container is simply full and therefore an alternative container is ought to be used or whether it is undergoing a malfunction. During my filed trip with one of the drivers, I could see this problem too at several locations. A big negativism of that is that card holders just store waste next to the original container they use instead of trying another one. This again causes more cleaning work for the Twente Milieu N.V. which of course has its price.

2.4.3 Issues in data management

Additionally to the trouble that is hardware related, also a variety of data management issues are observable in the collection process of the underground containers.



Measurement noise

Weighing of containers

There exists some measurement noise in the data infrastructure of the databases used to assess the need of collection. In this respect especially the data that is sent from the fleet to the "Welvaarts" server underlies rather frequent failures in data transmission. Because of that, the weighing of the containers is often outputted with gaps in the weighing history – which makes a thorough analysis of the relationship between clap openings and containers weight practically impossible for long term assessment.

Manual resetting

Manual resetting of the containers appears to be one major source of noise in the data with regards to the amount of clap openings before emptying. Drivers seem to forget to use the reset cards continuously, but also the system tends to not register the offered cards for resets. This can be confirmed in several cases due to personal observations during the field trip made. See also appendix A5 for suggestions and concerns of the collection operators regarding this issue.

Coordination between several databases

Currently two databases are used for the fill-rate determination and other analytical measures of the containers. First of all there is the database of Mic-o-Data, which is rather out-dated and lacks some very helpful features that the newly introduced B-waste database already incorporates. However, also the B-waste database seems to have some deficiencies according its user friendliness, but all in all it seems to be more workable than the Mic-o-Data one. So far, no link is established between these two databases, which makes a region-wide assessment of demand and fill procedures rather difficult to execute. There was a plan to integrate the Mic-o-Data database into the B-waste database, which is unfortunately not realised yet.

2.5 Conclusions regarding the current situation

The conclusions that can be drawn from the current situation are summarized below:

- The more urban the container infrastructure, the more containers are located in one location
- Weighing underlies data corruption of the Welvaarts server, which aggravates analytical assessment
- Manual resetting is also a reason for data pollution, both caused by man-made and technical failures
- Displays seem not to work properly, especially considering steaminess
- Vandalism occurs, mostly the lid and the activation button are affected
- The battery performance of the containers appears to be not as expected and ought to further investigated
- Several containers (especially in Enschede) have troubles with water leakages, mainly due to bad isolation of the ground pits.
- The true demand for multi-container locations has not been assessed deep enough and might be due to a review, since several locations show signs of under-utilized individual containers in a group (Dutch: "zuil")
- Furthermore, multi-container locations seem to have an uneven spread in waste among the containers on spot.
- The waste density for all containers is always assumed to be 0.10 kg per liter, which might be re-assessed, since it is necessary for a correct volume determination within a container.
- The truck fleet might be utilized more since at the moment the utilization is at 66.7% measured against a Twence-related bottleneck.
- Customer satisfaction and a reduction of the driven km of the truck fleet can be considered to be the primary performance indicators of Twente Milieu, handling costs have less importance, since the workforce is available anyways during the workday
- The Twente Milieu N.V. operates in a single shift cycle for the workforce per workday.
- On Saturdays neither collection of any container nor maintenance is executed.
- The regular shift for the collection underground containers starts at approximately 7:30 and end around 15:30-16:00
- Normally a Twence visit takes place twice a workday, the first around 11:30 the second in general around 15:00 too empty the trucks before the day finishing time.
- There are three different types of containers used by the Twente Milieu N.V.: 3,4 and 5 m^3 containers

3 Desired situation

In this chapter, the desired situation of the Twente Milieu N.V. will be discussed. In order to construct solution approaches that are favorable for the company and, in particular, for the problem owners involved their wishes and performance indicators have to be taken into account. In this context, the chapter is divided into two sections: one that describes a general vision of a well-functioning working environment as it is supposed to be according to the stakeholder and one focusing in depth on the on the requirements that are measurable before and during the actual implantation of the project.

Vision of a frictionless use of underground containers

As stated in the introductory chapter about the background of the Twente Milieu N.V. it came already visible that for the company much more than pure cost reduction ought to be considered in the solution approaches. Since one is not striving for profit maximization alone, especially the needs of all the stakeholders of the underground containers project and an eventual dynamic collection procedure have to be taken into account. In the case of Twente Milieu that are mainly the shareholding municipalities and the citizens of these. The expectations on a dynamic routing methodology are rather high. First of all, it has to guarantee that the performance of the Twente Milieu N.V. with regards to the visibility of the collection result is at least as good as at the moment and of course, possible much better. The inhabitants of the Twente region have to perceive that the management of the Twente Milieu took them seriously in their decision making about the implementation of a dynamic routing procedure that basically offers less visibility of the actual collection with the truck fleet. They have to be convinced about the fact that the less Twente Milieu is emptying their containers the better it is for their environment and of course that also they will benefit of a possible reduction in costs. Therefore, it is aimed to empty as much containers shortly before their due date as possible in order to keep the service level high. The service level lowers with every container that is seen as overloaded and thus was emptied too late. However, this goal also led to the current situation the Twente Milieu N.V. in which the number of depletions by far exceeds its actual demand. Consequently, one wants to try to empty the containers as close to their due dates as feasible without touching the service level where avoidable. Nevertheless, the service level constraint exists, it is also clear for the problem owners that the tighter this constraint is aimed at the more likely the situation of unnecessary emptying becomes. In addition, the needs of the workforce handling the underground containers – operational or maintaining – have to be addressed. Already this issue has been examined to a vast extent in Stellingwerff's work preceding this research.

Requirements for a successful implementation of a dynamic routing methodology

For the management team of Twente Milieu the following requirements have to be met in order to implement a potential dynamic waste collection process in practice:

- The service level has to be at least 97%, meaning that at maximum 3% of all containers emptied are collected too late in comparison to their due date
- The workforce is supposed to work five days a week from 7:30 a.m. until 4:00 p.m., preferably only collecting the really necessary containers on an efficient route (=shortest in time and km)
- If the capacity of a truck is not reached by Must-Go jobs alone during one route the potential new algorithm is allowed to smartly widen the container selection with May-Go jobs in order to increase the fill level and utilization degree of the fleet
- Shifts are possible in certain scenarios; In case the municipalities demand deep budget cuts of the Twente Milieu N.V. the possibility of two shifts ought to be considered – stretched out on an enlarged workday from earliest 7:00 a.m. to latest 9:00 p.m. The division of these shifts throughout the workday is not part of this assignment. If used this issue has to be solved with advanced scheduling and planning methodologies.
- In addition to the before mentioned point, also an enlargement upon a six-day work week is not unrealistic to examine on. However, Sundays will not be taken into consideration.
- The cost price to collect refusal per driven km is supposed to be lower than the today's value.
- Variability in the waste disposal pattern has to be minded in the new approach. Since it is already expected that the true demand of waste collection might vary strongly because of external events, like special occasions and a predicted sinus curve in refusal disposal the flexibility of the dynamic routing approach ought to be higher than with the current static method used.

- The issues described in the chapter “current situation” have to be focused on in the solution alternatives, since these are currently considered to be the biggest troublemakers with regards to basic requirements needed for an actual execution of a dynamic routing.

4 DATA ANALYSIS

Chapter 4 is concerning issues that are related to data collection and data analysis with respect to the underground containers project .

First of all, in section 4.1, a look is taken on sample measurements of container weight in comparison to their clap openings. Thereafter, a variety of disposal patterns are examined which also are used in the verification and validation of the simulation model used (chapter 6). Besides that also it is tried to get deeper insights from the provided financial data and its impacts on the simulation in general and other areas of interest.

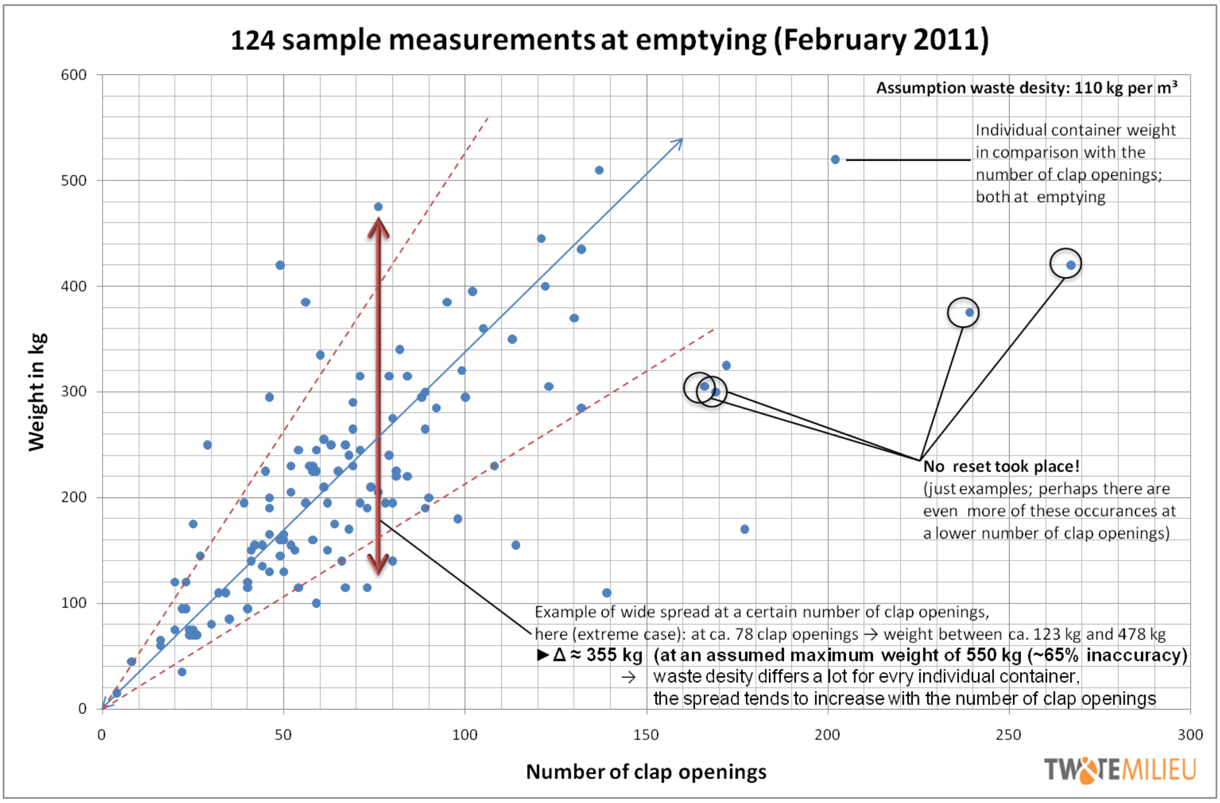
Section 4.2 is focusing on data mining with respect to the capacity of a 5m³ container. Here a paper model simulation is used to approximate the expected amount of lost capacity.

4.1 DATA COLLECTION AND CLEANING

In the section data collection and cleaning it is intended to detect information that is useful in a deeper analysis of the current situation and that can contribute to the solution alternatives which are elaborated on in chapter 7 and 8.

4.1.1 SAMPLE MEASUREMENTS

Since the weighing of the underground containers is not standardized in execution yet, it appeared to be necessary to conduct a range of sample measurements of the weight of several containers which were compared to their clap openings afterwards. Also visual checks on the actual volume stored have been performed by my colleague Arnout Dam and me in order to create insights on the ratio between clap openings/weight/volume. The following could be observed:



The figure above clearly shows an incredibly wide spread of the number of clap openings in relation to the weight measured. At the moment, Twente Milieu is still convinced that a volume determination of the waste inside an underground container is possible solely based on the known number of clap openings since the last reset of a container. However, this picture seems to show the opposite of this assumption, especially if for one weight unit would have the same density of the refusal is expected across all the containers in question, but the size of the deposits differ. Thus, the “soortelijke gewicht” per volume entity (Dutch) remains the same for all of the containers in that case, but the stored volume does not. Taking this into account, the difference in volume per container only seen the amount of openings of the lid is really huge. However, it is more likely that the density is different per unit of weight, which will decrease the previously mentioned observation. Still the differences would be too big to determine the volume within an individual container only due to the number of clap openings. In the figure this is depicted with the red line at about 78 clap openings. On one hand a container with that number open lid movements weight 123 kg while on the other hand another container with the same amount of clap openings accounted for 478 kg. That is already a difference of 365kg. If the assumptions can be trusted that a container only can fit approximately 550 kg in total (waste density of 130 kg / m³, true capacity of 4m³ assumed), it would mean that there exists an inaccuracy of 365/550*100= 65% within the volume determination procedure. This is of course way to high to make a sufficiently accurate schedule based on that data.

It is however most likely, that those big deviations in weight are mainly caused by a difference in density – unfortunately there is no data available at Twente Milieu to verify this for sure.

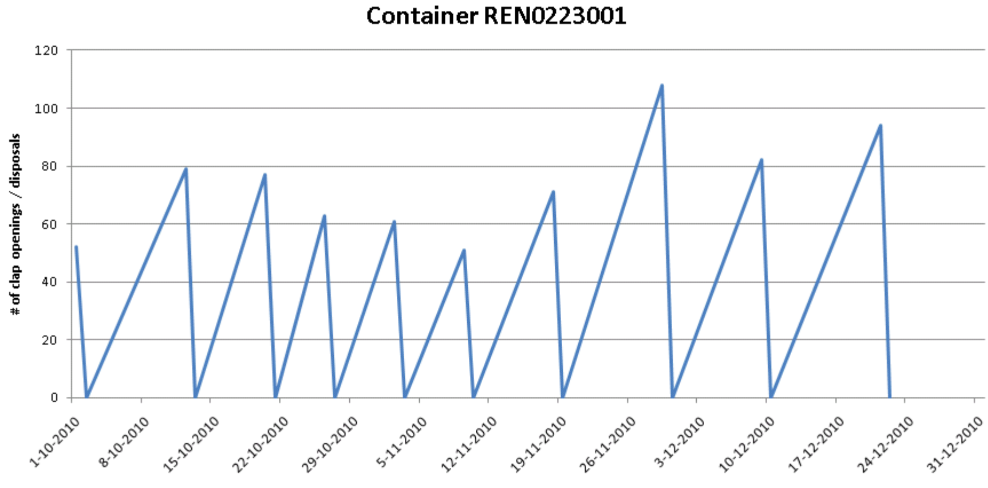
Moreover, other problems become visual in the figure; for instance clearly four measurement could be identified to be false due to faulty resets of the containers. I strongly guess, that this might also be the case for less extreme measurements; unfortunately, it was not yet possible to retrieve, whether container was put on reset according the standard. Faulty resetting is thus an additional source of measurement disturbances and should be tackled in the solution approaches.

Another interesting observation could be made with respect to the visual fill checks of a certain number of 5m³ container during the field trip. The most outstanding ones are listed below (also see appendix A5, A6:

- Container “Zuidenhagen”: physically full, no weight retrievable (guess: 450-500kg), 90 clap openings
  → 5-5.6kg per deposit, thus density of approx. 0.125kg/l with 4m³
- Container “Oude Markt”: physically full, 395kg, 102 clap openings
  → 3.87kg per deposit, thus density of approx. 0.098kg/l with 4m³
- Container “Tulpstraat”: physically full, 520kg, 202 clap openings
  → 2.56kg per deposit, thus density of approx. 0.13kg/l with 4m³

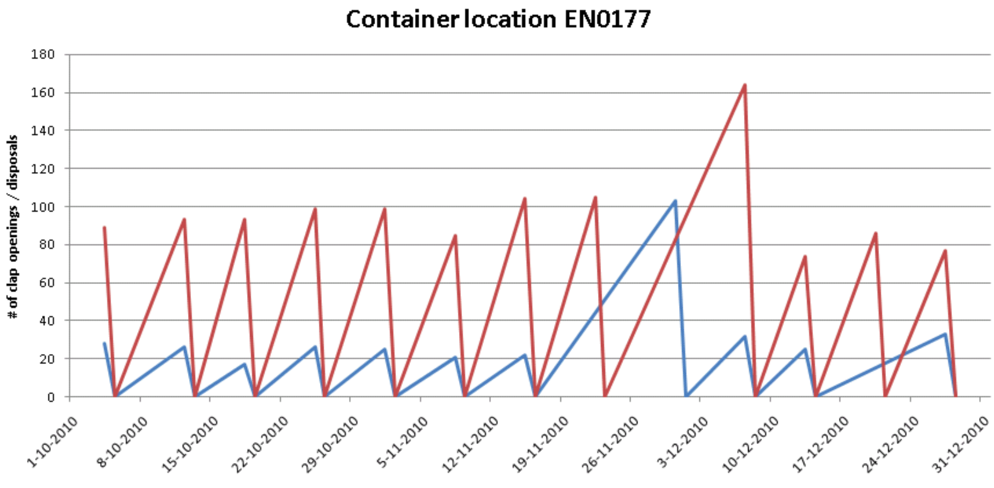
These examples of containers show once more, that a physically full container can vary quite a lot between the number of lid movements and the weight measured at the emptying. Here with this small amount of samples, already a difference of 112 clap openings and also a variation of 125kg could be observed. Seen the vast amount of containers the Twente Milieu N.V. has to empty even more extreme cases might occur.

4.1.2 DISPOSAL-RELATED DATA



Number of Disposals, Container REN0223001

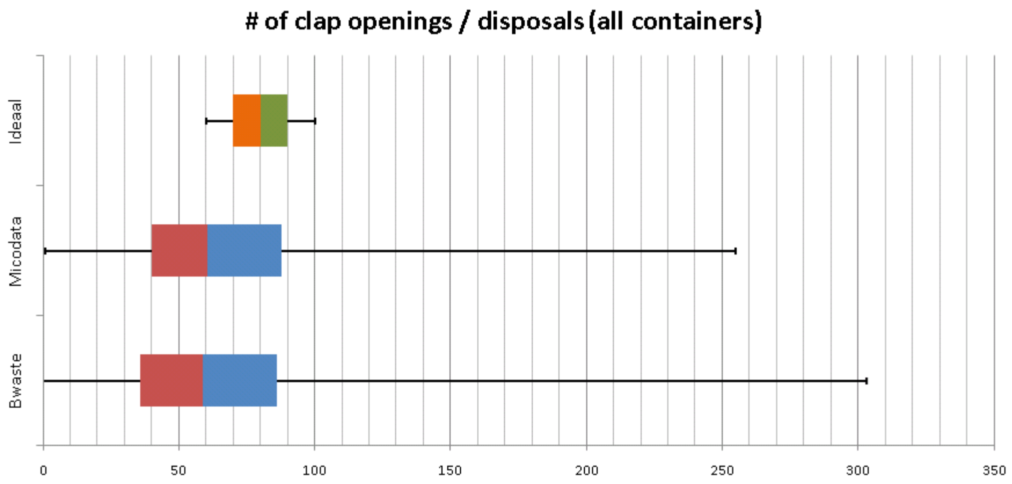
As can be seen in the figure above, the containers seem to be rather underutilized at emptying – at least if the clap openings are considered to be an indicator for the amount of refusal stored. It also becomes visible that the static planning sometimes reaches its constraints – especially looking at the date 26.11.2010 where it seems that the capacity was exceeded. Further, a manual adjustment of the planning is observable, based on the experience of drivers deciding to collect the container later than initially proposed by the collection schedule.



Unequal use of multiple containers at the same container location

The chart above was retrieved from the B-waste database used at Twente Milieu and clearly indicates that the capacity of this multi-container location has been overestimated beforehand. One could argue that it might be an exceptional picture, however it is not. Many cases of underutilized second or third containers at a multi-container location could be found. The reason why this graph behavior is occurring is due to the assumptions made when the block containers have been removed. It was supposed that two of the block containers are equal to the demand of one underground container, while the true demand was not deeply reviewed again. Therefore is appears that Twente Milieu has an overcapacity of underground containers, that might not be necessary in several location. Replacing them to locations where old block containers are removed at the moment would cost some efforts and money, but in the end it might save Twente Milieu a lot.

Moreover it can be said that, even though there is apparent overcapacity the distribution of the deposits for multi-container locations is rather uneven. Solving this issue might extend the duration until an entire location is full. If the containers at one location could be full at once the collection would become even profitable for the Twente Milieu N.V., since only a single pick-up would be needed instead of several.

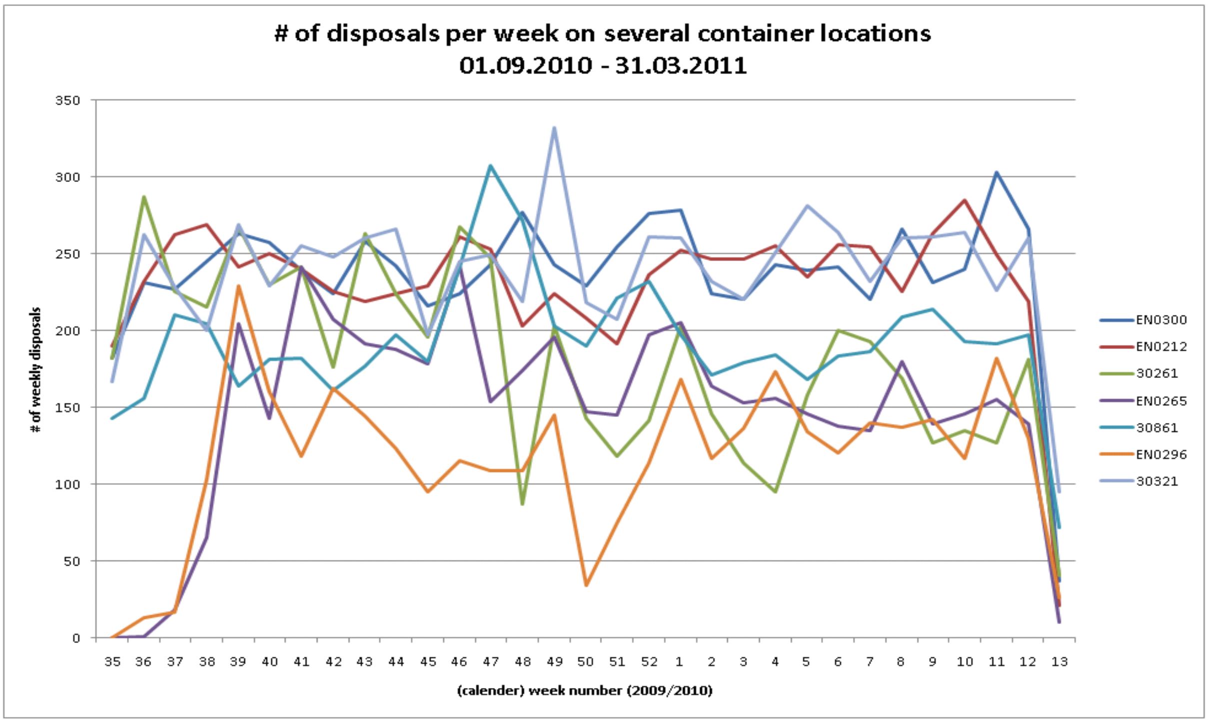


Boxplot number of disposals (B-Waste and Mic-o-data database)

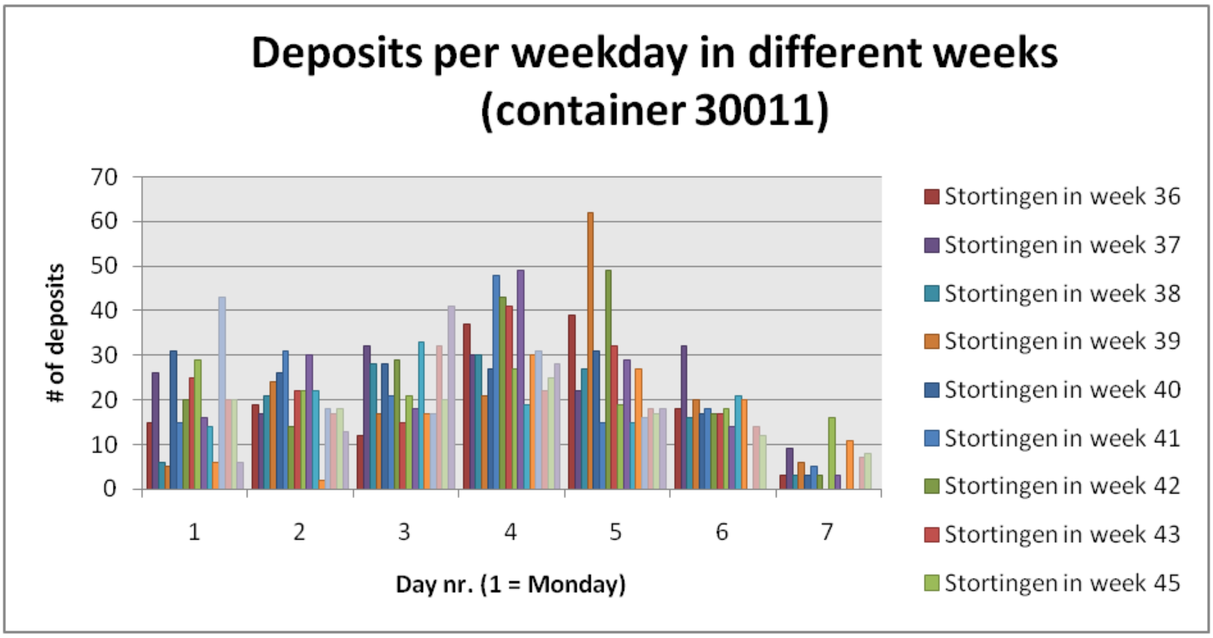
The chart "# of clap openings /disposals (all containers)" is a good indicator how wide the spread is in the collection process of Twente Milieu. Data was retrieved from the two main databases used at the company – Mic-o-Data and B-waste. It is depicted that some containers are even emptied when they are still completely empty while others seem to reach 300 clap-openings for one collection cycle. The extreme numbers might be due to manual resetting mistakes, however also looking at the second and third quartiles of the box plots clearly show that emptying normally take place between 40 and 85 clap openings while B-waste and Mic-o-Data even claim that 100 should represent a full container. The sample measurements already showed that the spread between a physically full container and a container full in the databases can differ immensely. Thus, it should be aimed to get Twente Milieu in the situation of the first box plot, depicting the ideal situation. Here it becomes visible that an 80% fill rate of the containers is desired and that the spread of the outliers ought not to undercut a line of 60% fill of a container, given the assumption that the databases would actually show the true fill rate in percent.

Weekly demand

More graphs in the appendix A34.



Number of Disposals based on (Calendar) weeks, several Container locations



The figures above show a rather large deviation in clap openings throughout the days of one week and furthermore a very sinus-like change (with varying altitudes) in demand from one week to another. To have a complete picture about this behavior actually all of the containers that are possessed by Twente Milieu or the connected municipalities ought to the analyzed. However, this would explode the workload for this study and therefore only indication will be reported.

The above mentioned sinus-like deviation from week to week seems to be a good argument for a dynamic routing approach, since static planning sometime would empty way too much or also too few. According to (Ola M. Johansson, 2008) this fact is very valuable, since a reactive dynamic approach has a lot of cost saving potential.

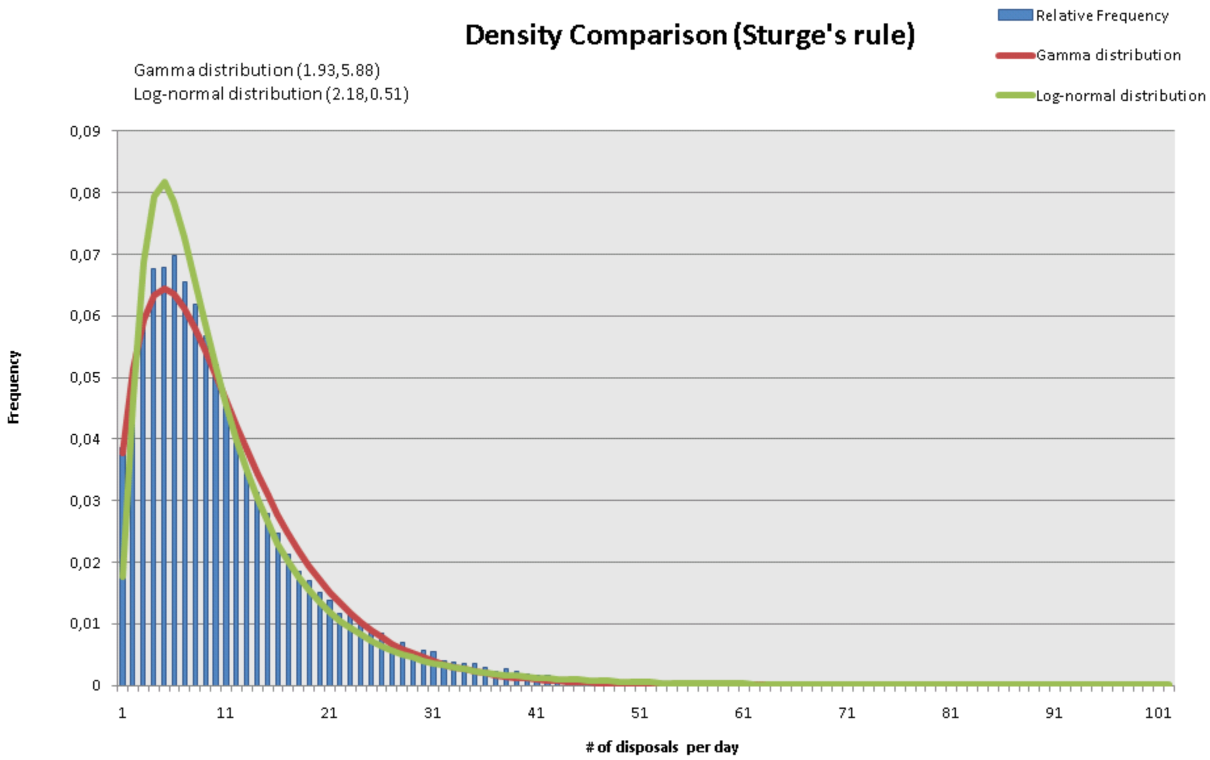
It seems relatively sure that Sundays are the days where the least amount is stored in all of the containers while in the course of the workweek (Monday to Friday) a rather gradually increasing pattern becomes visible.

Deposits per day (simulation related)

To analyse the behaviour of the number of deposits per day, data was assessed from 6 months of container usage. In total 52522 entries per found that represent the number of clap openings of each of the 450 containers that participated within the Twente Region.

The aim was to find a fitting input distribution of the deposits per day for the simulation model (described in chapter "Simulation model set-up"); the summary statistics are as follows:

Summary Statistics	
Num. of Obs. (n)	52521
Mean	11.34752
Mode	6
Median	9
Max	103
Min	1
Range	102
Std. Dev.	9.223235
Variance	85.06807
Skewness	1.922652
Coeff. Of Variation (cv)	0.812798
Kurtosis	5.72384



A statistical chi-square test has been executed (see appendix A14) with the conclusion that the proposed Gamma distribution with an alpha of 1.93 and a beta of 5.88 is fitting to the original input data. Therefore, this distribution with the mentioned parameters will be used in the simulation model set-up.

Maximum workload per workday

In order to find a constraining threshold for several dynamic options that include May-Go jobs and in particular for the static planning option, the average number of emptyings done per day at Twente Milieu were researched. Therefore the pure original schedule of the collection in Hengelo and Enschede was taken (which is not followed in reality) and has been modified based on drivers experience according the inclusion of May-Go jobs. The outcome was that on average 21.6% of the 406 containers were emptied per workday. This subsequently has been rounded up to 22% and is valid input for the validation of the static policy in the simulation model used later on. (Also see calculations in appendix A32)

Analysis of financial data

An analysis of the financial data of appendix A35 shows that a container is on average emptied 56.63 times on a yearly basis. This conclusion will be helpful in the verification phase of the system performance of the simulation model. Furthermore, per annum around 25,500 emptyings of underground containers take place with 451 containers. For a scenario of 378 containers this would mean ca. 21403 emptyings per year. The cost price per emptying was calculated to be €15.26. Besides, it emerged that the average time a collection takes of an entire container location is around 10 minutes and 37 seconds. This is much more than the time used in the existing simulation model of Stellingwerff, however there the hauling time is considered per container and not per location.

Size of truck fleet based on financial data

In the chart of appendix A30 calculations have been performed under several assumptions. In total it appears that even with a fluctuation in daily deposits of 20% with an extension of the work duration per day and workable Saturdays the truck fleet does not have to be increased. This would be given the situation that containers are only emptied when they are 90+ % full. With the standard work time as it is now, the fleet would have to double (4 trucks). However if the low average fill rate of the containers stays as low as it is now the fleet would have to more than triple in comparison the situation Twente Milieu is used to at the moment.

4.2 Conclusions regarding the data analysis

- The lost volume in a 5m³ container is not only 10% as currently assumed but between 22 and 23% of the 5m³ with a confidence of 90%. Meaning that actual volume that can be used for the deposits is only around 3.9m³.
- With a confidence of 95%, the lost volume in a 5m³ container is between 21.6% and 26.6% of the 5m³, meaning that in this case the actual volume that can be used for the deposits is only around 4m³ - taking the lower CI-bound for assessment.
- The filling procedure in a container follows a gradually growing pyramid-like shape (depicted in the previous section).
- A container is not always physically full with the same amount of waste bags deposited. This number might vary a lot in reality due to different fall procedures of the individual bags.
- Confirmation: capacity issues can be solved by the introduction of shifts and Saturday work connected to the opening times of Twence. No purchase of additional truck would be needed to satisfy the collection of 1500 containers under this circumstance. The utilization of the truck fleet would be increased dramatically.
- The underground containers are emptied 56.62 times per year in 2010 which corresponds to collection frequency of 1.09 times per week for an individual container
- The cost price per emptying is €15.26.
- Currently the Twente Milieu N.V. handles a cost-plus approach towards its customer with a profit margin of four percent added to the cost price mentioned in the previous bullet.
- Per annum 25536 emptyings were performed in 2010.
- The deposits per day were assessed by more than 52500 data points and it became visible that a Gamma (1.93, 5.88) distribution was a good fit for this issue. A statistical test has been performed and with an alpha error of 5% the distribution is considered to be a fit between the expected and the actual observations.
- The number of deposits seems to fluctuate heavily from weekday to weekday and from week to week. Seasonal fluctuations became visible as well. There were two sorts of deviation in the demand that can be observed: a sinus-like one and uniform one.
- It appears that there is a huge spread in the assumed correlation between the weighing data of containers and the number of clap openings. In the sample data a maximum spread of 365kg at 75 clap openings were found – that is a tolerance of around 65% of the assumed total maximum weight of a container (550kg). This inaccuracy seems too big to me to draw conclusions on the volume inside of a container based on the clap openings alone.
- The demand of containers at multi-container locations ought to be reviewed, since several containers show signs of under utilization. Perhaps the assumption that two block container represents one underground container does not hold anymore
- The demand in single containers is strongly fluctuating, sometime the database give fill rate of 100% was exceeded and the static schedule is not followed by the drivers. This is an indication that fill rate based on the number of clap openings is not working very well.
- Data pollution is a serious issue in the analysis of the containers data and is caused by several problems (see previous chapter)

5 Literature study

The aim of this chapter is to get deeper insights into the already existing literature and the conclusions that can be derived from it in order to solve the existing problems for the Twente Milieu N.V. that have been discussed in the chapters 1 and 2. Here there is given an overview about useful literature regarding the inventory routing problem (IRP, section 5.1), relevant cases within the area of solid waste management (section 5.2) and application possibilities of sensors in solid waste collection (section 5.3). Finally, there is a summary of the findings with respect to the literature study that can be found at the end of this chapter in section 5.4.

5.1 Vehicle Routing Problem (VRP)

In general the problem that the Twente Milieu is facing can be seen as part of a VRP (Vehicle Routing Problem). This area of logistical problems has already been widely been researched on as for example by Psaraftis, H.N. (1988), Toth, P.; Vigo, D. (2001) or Bertsimas, D.J.; Van Ryzin, G. (1991). According to Cordeau et al. (1997), for instance, a routing problem has to involve the following characteristics to the within the framework of a VRP:

- An individual visit point has only to be included in precisely one route and not more than that
- The used fleet has to have sufficient capacity to satisfy the demand constraints of the visit points that are included in the routing system
- The number of vehicles is normally ought to be as small as possible to satisfy the demand of the visit points
- The goal of a VRP is it to finally minimize the sum of time spent on all of the routes.

The problem of Twente Milieu satisfies all of the above mentioned criteria in order to belong to the VRP group; however an important aspect cannot been tackled by the VRP solution approaches – the matter of a finite amount of volume that has to the transported between the visit points. Therefore, as already declared in the work of Stellingwerff, the issue of container collection is not a pure VRP. The routing itself is important, but not the most important here – therefore another type of logistical problems came into the focus of the research carried out at the Twente Milieu N.V. – the IRP.

5.2 The inventory routing problem

An IRP has additional features that try to complete the VRP with respect to capacity constraints of the fleet and the corresponding visit points involved. It tries to make a connection between the VRP based routing and the inventory that has to be moved from point to point. Again the literature on this field of study is rather extensive. As Stellingwerff pointed out an overview on various types of IRP's can be found under the reference of Andersson et al. (2004). For Twente Milieu, however especially the IRP that has been described by (Campbell et al., 1998) is of great importance. The IRP normally have the following in common:

- One certain type of product is distributed repetitively over a set of several customers taking a given length of service duration into account
- All of the customers share a single replenishment source (a depot)
- The visit points (or customers) use up the product regarding a given rate in a certain amount of time
- The fact mentioned in the bullet above is the reason that the visit points get replenished after a while, however here the capacity restrictions become important, since there is only a finite amount of capacity available per visit point.

Seen these characteristics of an IRP the following trade-off decisions are considered:

- At which point in time should a customer be delivered to fill up its stock? (selection)
- How much ought to be delivered in that situation? (demand determination)
- What is the best order and therefore route to deliver the set of selected customers? (routing)

However, in the case of the Twente Milieu N.V. the container collection does not represent a process where replenishment is needed but release of volume into the fleet. Taking this into consideration, it can be spoken about a RIRP (Reverse Inventory Routing Problem).

This specific adaption of the IRP has been researched in depth in the thesis of Stellingwerff (2011) for the case of Twente Milieu.

5.3 Solid waste management

With respect to literature that considers in particular issues in waste management the amount of articles that can be found is rather small. Interesting issues were described for example by (Byung-In Kim, 2006) in his article about waste collection that treated an approach of VRP's with time windows in order to decrease the amount travelled kilometers. The ant colony approach by (Nikolaos V. Karadimas, 2005) is also rather interesting to consider. In this article artificial ants (trucks) are searching the area for the most optimal route for a given set of container locations. This done by at the beginning random cycling through the area and leaving a "pheromone trail" in the intensity of the found solution value of travelled kilometers. Thus a route that has a high pheromone density is more and more followed by the other artificial ants until the best route is found. However, at Twente Milieu the actual selection of the container set that has to be emptied is of higher priority than the actual routing, since the distance between most of the container locations is rather small and the drivers appear to have enough experience in driving in the Twente region that they know which way to take in order to decrease the amount of driven kilometers.

The most related work found – next to the preceding study of Stellingwerff, of course – that is connected to the case of Twente Milieu is the article "The effect of dynamic scheduling and routing in a solid waste management system" by Ola M. Johansson (2005). This article focuses on a dynamic waste collection approach with 3300 containers (above-ground) in the Swedish city Malmø. In the research set-up one had real-time access on the fill status of each container used. Alike the research done by Stellingwerff, Johansson used discrete event simulation and analytical modeling in order to access the performance of the waste collection procedures proposed. He concluded that dynamic routing can decrease operating costs and the hauling distances, increase the collection cycle per container and therefore also can cause a reduction in labor costs. The situation is actually very similar to the one of Twente Milieu, since also a crane equipped truck fleet was used of the collection. However a vital difference in the use of tilt sensors for reset which is done manually at Twente Milieu. Moreover, the Swedish containers had two infrared optical sensors in order to access a May-Go level and a Must-Go level, which was connected to a penalty if the collection took longer than 24 hours (48 hours in the weekend) after the second level was reached by the refusal altitude. Also only containers that had reached the first level were included in the selection procedure in order to prevent that containers are taken less than May-Go level full.

The Primary performance indicators used by Johansson et al. are, amongst others, labour, penalty, hauling, operation costs – so they are relatively similar to the ones that have been used in Stellingwerff's research which makes the studies even more comparable.

Four different dynamic policies were proposed by Johansson et al:

1. *Static scheduling and static routing*
   - Once planning of frequency of each container, routing is done in the same order throughout the simulation without adaption
2. *Dynamic scheduling and dynamic routing*
   - Fully event driven methodology. Includes only Must Go containers during all working days, except for Fridays. On Fridays also May Go containers are allowed for collection in order to decrease the amount of overfull containers in the weekend. No rescheduling performed ("alarm" while executing a ride is postponed one day). The routing order starts always with the Must Go jobs. Like with the other dynamic options, it is presumed that enough operational capacity is available to handle the system size of containers.
3. *Dynamic scheduling and dynamic routing to "almost" full containers*
   - Similar to the second policy, however now the routing order can also be changed between Must Go and May Go jobs, depending of the "attractiveness" of a May Go container.
4. *Static scheduling and dynamic routing to "almost" full containers*
   - Similar to the first policy. However now the routing is done in order of the "attractiveness" of the Must-Go and May-Go jobs.

As a result it is found that policy 2 is the most optimal for large systems (>100 containers) since the distances between the containers are small and the main costs derive from the handling costs instead of the hauling expenses. Further he claims that the most savings can be obtained in unstable environments with high demand fluctuation. The static policies performed acceptable for small system size, however at all levels they included a higher labour force involvement than the dynamic options.

The research conducted by Stellingwerff (2011) under the supervision of Mes should be used as an additional reference point for the reader of this report, since the study described here is heavily based on the work that has been done before.

5.5 Conclusions of the literature study

- The more instable the system the higher the cost saving potential in a solid waste management system.
- Accepting May-Go jobs only on Fridays is very profitable. The focus should be laid on the Must-Go jobs and not on the May-Go jobs in order to increase the system performance
- The problem Twente Milieu is facing is a reverse IRP with focus on solid waste management.
- Optical sensors have been used in Johansson's research – more precisely infrared sensors – to measure a May Go and a Must-Go level within the individual containers. Apparently this did not cause big uncertainties about the actual fill rate.
- For dense systems in urban areas the handling costs are the most influential for a cost reduction – in contrary the travel costs are the least influential, since the distances between containers are very small. Therefore the container selection appears to be more impactful to the overall objective than the routing itself.
- Stellingwerff's work shows a lot of overlap with this research and it a valuable reference point for understanding the decisions that have been made throughout this research.
- The literature on dynamic waste collection is rather scarce and currently gives a lot of space for extension of the existing knowledge - especially in the area of the container selection procedure. On routing more research has been carried out.

6 Simulation model set-up

In this chapter the simulation model will be described that will be used to evaluate different routing and container selection methods in order to find an approach that satisfies the desired situation proposed by the Twente Milieu N.V. First of all the model itself will be described shortly. Since, this study is mainly based on a previous master assignment executed on this field only relevant features will be mentioned and furthermore essential changes will be explained. The same counts for the sections about the level of detail, assumptions made and the solution requirements. For deeper insights into this section it is handy to consult the work of Stellingwerff (2011). In the following the experimental design of this study will be discussed, as well as the settings used for the model and verification and validation attempt in order to find a realistic base scenario. In section 6.8 the performance measurement procedure with its key, primary and secondary indicators is explained. At the end of chapter 6 all relevant conclusions with respect to the simulation model set up will be provided.

6.1 System Description

Basically the same simulation system has been used in this study as in Stellingwerff's study, however with several adaptations made to it. These changes mainly consider the KPI's used, the implementation of the balancing algorithm and a standard use of rescheduling when a truck is in danger to overflow.

The new KPI will be discussed later on in the section on performance measurement within Twente Milieu and the simulation study (see section 6.8). The newly adapted balancing approach is more intuitive now, since the balancing only takes place starting with a Thursday. Here it is tried to pull the amount of work that has to be done on Friday towards the operations of that particular Thursday. Thereafter it is also for the expected workload on Fridays that is again based on the balancing of the weekend demand. Mondays to Wednesdays are not balanced, since only the weekend gap causes severe peaks in the Monday collections. For the rest the balancing formula remains unchanged, see chapter 6.6.1 in Stellingwerff's study.

There are two simulation scenarios developed in order to test the performance of the different planning methodologies for the Twente Milieu N.V.: a 378 container scenario and a 700 container scenario.

For both of them the following information is valid:

- The travel distances are calculated via a special application that can access Google Maps
- The handling times can be split up into
  - A Twence visit takes on average 15 minutes
  - Container handling is depended on the maximum workload of containers allowed during a workday in reality this amount is approximately equal to 75 containers per day. However, also seen the fact the on a 8-hour workday – which already includes one hour for breaks and two Twence visits – a realistic amount of containers to be emptied per day is 55. Based on the above mentioned two numbers the handling time per container is set on 4 minutes per collection per individual container.
- The input distribution for the deposits per day is determined to be a Gamma distribution with a mean of 9.5 and a variation of 55.86. (See chapter "Data Analysis"). This input is taken over the average of the Twente region, so that the mean / variance ratio stay the same.

6.2 Level of Detail

In the simulation study it is focussed on two scenarios with respect to the collection of refusal executed by the Twente Milieu N.V. The first scenario considers a setup with 378 containers; the second scenario is using an amount of 700 containers in order to assess the performance of various planning methodologies that will be explained later on in this chapter of the report.

6.3 Planning methodologies tested: Description

Static planning

The static planning policy only assess the scheduling of the containers, partially based on the maximum allowed number of jobs that can be done during one workday and the potential average demand per container. Once the schedule is established it is not changed anymore. The routing is based on nearest insertion and is also only done once. During a simulation run neither the schedule of collectable containers nor the routes are altered.

Normal Dynamic Planning

Normal dynamic planning is the basic dynamic approach that mainly focuses on the collection of Must-Go jobs. Whenever a container gets red-flagged as Must-Go job it is included in the schedule. Several rescheduling options are tested on this policy in the exploration phase in order to assess their effect on the overall performance.

Dynamic Planning with Balancing

The dynamic planning option that is including balancing works as proposed in the research of Stellingwerff (2011). Only Must-Go jobs are considered, but this time the expected workload is balanced in order to avoid extremely large collection routes on one day, while on another day nothing is to do. This might happen in the normal dynamic approach which can be reviewed in the chapter concerning the computational results.

Dynamic Planning with May-Go jobs

The dynamic planning policy with May-Go jobs operates rather similar to the normal dynamic option. The main difference is now that not only Must-Go jobs are considered for the scheduling, but also May-Go jobs. With this policy various Must-Go / May Go combinations will be examined in order to find the trade-off between short-term and long-term scheduling

Dynamic Planning with fixed amount of Must- and May-Go jobs

Dynamic Planning with a fixed amount of May-Go jobs is very similar to the previous option that does not include a constraint on the total amount of jobs scheduled. Here it is worked with StaticMax (the maximum allowance of collectable containers per workday). This is done to avoid massive workloads on one day in comparison to the others. Therefore it has a similar effect like the balancing procedure.

Dynamic Planning with Balancing and May-Go jobs

The dynamic planning policy with balancing and May-Go jobs is combining the features of the balancing and May-Go option. The main focus is on cost reduction through the inclusion of May-Go jobs and the "workability" throughout on work week.

Dynamic Planning with Balancing with fixed amount of Must-Go / May-Go jobs

Dynamic planning with balancing under the consideration of a fixed amount of Must and May-Go jobs is based in the same principles as the previous policy, but now the amount of jobs that can be scheduled are limited by the maximum amount of jobs allowed for one day.

6.5 Experimental Design

Experimental Factors and Range

In this section the essential experimental factors and settings will be elaborated on in order to give the reader an insight of the general simulation approach that has been followed. Certain factors have more impact on the results than others; for this purpose the section focussing on the exploration of factor design the several stages will be explained when a variety of factors becomes fixed in the simulation. This occurs, if a certain setting of a particular factor more or less has been proven to be the most beneficial for the outcome of the simulation. Since, the computational time increases dramatically throughout a simulation run with a high number of factors and settings for those factors, it should be intended to decrease the amount of variable components in a simulation as much as possible.
The experimental factors that are used in the simulation study for the Twente milieu N.V. are the following:

- ***WorkDays****:* workdays in a week. Range: 5 to 6 (5 = Monday until Friday, 6 = Monday until Saturday.
- ***Balancing****:* If the balancing option is of "true" the balancing algorithm proposed by Stellingwerff's research is used in order to balance respectively smooth the workload of the collection process throughout the work week.
- ***MayGo****:* Selection this option will cause the inclusion of May-Go jobs in the selection procedure of all containers to be emptied during one workday. The definition of a May-Go job can be found prior to chapter 1.
- ***VarFactor****:* This value determines how much deviation in the deposits will be introduced in the simulation study. It refers to the VarType.
- ***VarType****:*
    a. ***Norm***: This stands for "normal" and therefore it represents the default scenario of the simulation settings
    b. ***Mean****:* The mean variation causes a change in the mean of the deposits made per day. The VarFactor is multiplied with the default mean, thus a VarFactor of 1 does not give not any effect.
    c. ***Stdev****:* The standard deviation will be multiplied with the VarFactor, VarFact =1 is the default and also gives no effect
    d. ***Expec****:* This experimental factor considers the study of consequently over- or underestimation of the mean of the deposits per day. The VarFactor is multiplied with the mean that is expected at Twente Milieu while the actual mean and the actual standard deviation remains intact. A VarFactor of 1 does not have any effect
    e. ***Uniform***: This option is similar to the mean factor, however now the demand size will be assessed every day based on a uniform drawing of lots. Based on the VarFactor the mean therefore will fluctuate around the default mean for the value in percent that the VarFacor indicates. Thus a VarFactor of 0.2 mean that the daily mean will deviate 20% from the original mean in both the negative and the positive way. A VarFactor of 0 does not have any effect and represents the default scenario.
    f. ***Sinus****:* This factor is again similar to the mean factor. However now the deviation from the standard mean is determined by the percent value that is given by the VarFactor (wave altitude) and the variable SinPeriod prescribing the wave length. On a daily basis the mean will differ from the standard, however on the long-term the observed mean will be equal to the standard mean.
    g. ***StaticMax****:* Here the maximum number of containers that are ought to be emptied per workday are determined. This factor is especially of importance for the static planning and other dynamic planning options that use a fixed amount of containers that are collected per day – like for instance Dynamic

MayGoFixed and Dynamic AllFixed. Normally the default is considered to produce an average container fill rate of 57% in the static planning option in order to give a realistic default scenario.

Attention: With the factors Mean, Stdev and Expec the VarFactor is always around a value of 1 while with the factors Sinus and Uniform the VarFacor has to be between 0 and 1.

- ***Reschedule options:*** The effect of different reschedule options is tried to be visualized by this factor, there are four options that have been taken into consideration:
  (1) No rescheduling. If a truck has to empty a containers and it is expected that the container content does not fit inside the truck anymore, the particular truck is sent to Twence and will return to the same spot in order to finish it initially scheduled route.
  (2) A truck will always be re-planned for a new route when it arrives at Twence
  (3) This option is similar to option 0, however, if a truck arrives at Twence due to an order it could not fulfill, it will be re-planned, thus does not return to the same initial route.
  (4) This option is the same as the previous one, however now, if a truck arrives at Twence all of the fleet will be due to re-planning
- ***MustGoDay****:* This is important for the Must-Go jobs. A job will be considered a Must-Go job, if the container is expected to be full within the value inputted here in days.
- ***MayGoDay****:* The May-Go day is the threshold value for a May-Go job. Furthermore it works similar to the Must-Go day. This threshold is variable in the simulation.
- ***Sensors***: This experimental factor has been included, since it can show the effect if not only the volume in the containers is assumed via the number of clap openings, but is actually known for central planning. The only uncertainty left is the point in time when the containers will be physically full (Must-Go day).
- ***SinPeriod****:* This is one of the main inputs for the sinus variation. Here the wave length is prescribed to the model (read more under VarType Sinus).

Planning method comparison

The various planning methodologies will be examined in the following steps:

1. *Exploration:* The optimal setting for a certain approach still has to be found yet. The approaches will be evaluated with different input settings from which the best working will be chosen. Once these settings are fixed, they will not be changed due to the high computational efforts that are related.
2. *Comparison:* The performance of the different dynamic methods will be researched and the best performing dynamic policy will be chosen for step 3.
3. *Improvement:* The improvement potential of the best performing dynamic planning approach is benchmarked against the default method which described the current collection process.

6.7 Verification & validation of the base scenario

Validation of the used simulation model is necessary to see whether the reality was approached accurately enough by the model used. This is furthermore of outmost importance for a benchmarking on possible improvements based on several other strategies. The validation is done with data from the actual operations and it is intended to prove that the assumptions incorporated in the model were well chosen. For the case of the Twente Milieu N.V. the validation process is rather difficult to execute, since the current collection process has a lot of influences of human behaviour (e.g. random experience-based addition of May-Go jobs in existing routes). The static policy that has been newly designed for this study will be used of the validation and later-on also for the benchmarking of improvements the various dynamic policies produced. Referring to the interviews I conducted with collection operators it was mentioned that per day normally 60 containers can be seen as the maximum workload for one truck alone. Moreover, it came to light that around 22% of the total container population is emptied throughout one single workday at the moment and that this is also including the addition of May-Go jobs that can be smartly incorporated in existing routes. This natural system is not easy to implement in a simulation, therefore it has been chosen not to make random cyclic schedules for all of the containers, but to base the time that they are due to collection on the expected amount of refusal that each container will receive. This approach appeared to work quite well in practice and it was possible to come relatively close to the real-life system performance. For the general system validation the following data is used:

- The management of the Twente Milieu submitted that on an average work day around 22% of the container population is emptied with the collection fleet. Taking this number into account, for a 378 containers scenario, the amount of containers that are collected on a daily basis is around the 85. This means that there are 415 emptyings per week and ca. 21613 emptyings per year. Consequently, a container is collected 21621.5/378=57.2 times per year – which comes very close to the 56.86 times (respectively 1.098 times per week) that emerged in the data analysis.
- Emptying 83 containers per day yields around 63% fill rate per container on an average basis. From the Customer Settings in the simulation model it can be retrieved that the daily deposal volume equals 148069.565 liter – what is equal to 391.72 liter per container. Conclusively, 365 * 391.72 / 57.2 = ca. 2500 liter are stored in every container before it gets emptied. This is a fill rate of 62.5%.
- In Stellingwerff's work a value of around 55% have been estimated as average container fill, however with the assumption that a container can fit 4800 liter until it is full. 55% of 4800 liters equals 2640 liter. Thus an average fill of 2500 appears to be realistic enough approach practice.

In order to benchmark the improvements yield with the various dynamic planning policies, a static policy has been developed. The following principles are the basis for the static planning algorithm:

- The target is 75% fill rate on an average basis for every collection. The desired inter-arrival time between two collections is determined by 0.75 * the capacity of a container / mean of the deposits * mean of the volume of a deposit
- The desired number of emptying per day is determined based on data given by the Twente Milieu N.V. of 22% of the total number of containers
- Every container sets a time for the next emptying after a collection took place. Now this new collection event is scheduled on the current time plus the adapted inter-arrival time as can be reviewed in the first bullet.
- At the beginning of a day all of the containers are sorted based on their collection date. The first containers that fall within the range of the maximum number of collections allowed per workday are written on the schedule for a certain day. The inter-arrival time is therefore not used directly, but just as an auxiliary agent for the selection of the containers. The reason for this set-up is that otherwise the effects of weekends have to be modeled explicitly – which is now unnecessary. At the end this is a static model, since the selection is independent of the number of clap openings, but it uses some smartness, which would also be the case in reality. It is not a truly cyclic model, since the containers are scheduled on predetermined dates, however the time between two collections of a container stay relatively similar which results in almost periodic schedules.
- The only problem with the above mentioned policy is the start of the simulation, because the containers have not been emptied beforehand and therefore do not calculate a next appointment for collection. Due to this reason the policy fills the containers based on a uniform draw. This is done by directly calculating the Days Left per container. If there are containers that have not been emptied before they are getting preference and are sorted based on the data of their Days Left.

6.8 Performance Measurements

Within the simulation study a wide variety of performance data was collected in order to be analyzed later on. According to the performance measurement there can be made a distinction between three categories of indicators used: the KPI (or Key Performance Indicator), the primary performance indicator and the higher level performance indicators.

Key performance indicator

As KPI the total costs per litres refusal collected have been established (TC/L). The reason to establish only one single performance indicator that is already incorporating the main requirements set by the Twente Milieu N.V. is relatively simple. Since the execution of the simulation runs was taking a vast amount of computational efforts and a lot of different simulation settings under various factors had to be evaluated – especially in the initial adjustment phase – the choice for a single performance indicator that made improvements as well as deteriorations in performance visible very fast, became favourable. The TC/L (total cost per collected liter refusal) consists out of the following fractions:

- The travel costs per liter collected
- The penalty for collection one liter of waste too late (after a container already has been considered overloaded)
- The handling costs per liter collected

Thus, the data of the amount travelled, the number of lately emptied containers in comparison to the system size and the amount of handling time (the actual emptying action) were gathered.
The ratio of these three components in the objective function of the simulation is as depicted in the table below:

Costs travel	1	Costs handling	0.5	Costs surplus (too late)	0.7

As can be seen; the travel costs are considered to be the most influential with respect to the overall performance, while handling on the other hand only contributes half of the costs to the total cost. Thus, travelling one kilometer more is considered twice as worse than emptying one additional minute. Also emptying too late is penalized harder than longer handling times, however less than the travelling, since the main objective of the simulations was to decrease the mileage of the collection fleet that Twente Milieu uses. The ratio that is presented above tried to reflect the importance of each of the individual cost factor towards Twente Milieu's perception for efficiency, especially with focus on possible cost savings that might emerge through the simulation study that has been carried out during this research. Again it should become clear that reducing driven kilometers in the collection process is the main goal of this study, therefore these costs are weighed the heaviest. Handlin is chosen to be 0.5 since the workforce is not flexible at Twente Milieu at this moment, thus if more hauling is done, the fixed costs Twente Milieu already has to carry due to its employees will not change – however still hauling should have some penalty, otherwise these times would exploited too unrealistically by the simulation model. Emptying too later is bad, but in order to not focus only on the customer satisfaction, which would lead to heavily increased travelling, the trade-off had to be made to chose a value of 0.7.

Primary performance indicators

The primary performance indicators are the main input for the key performance indicator which represents a weighed reflection of the initial components. Therefore, travel costs, penalty costs (at surplus) and handling costs can be seen as primary performance indicators. This type of indicators is especially important when there is a tie between the KPI of one proposed collection method in comparison to another one. In case of uncertainty which method to chose the primary indicators can help to make that decision easier, since a trade-off in the own needs can be made.

A list of the higher level performance indicators used in the simulation model and the related data collection can be found in appendix A36.

6.9 Conclusions w.r.t. the simulation model set-up

- The primary performance indicators are handling, travel and penalty costs (for emptying too late)
- The KPI (key performance indicator) is total costs per liter of collected waste, consisting out of the previously mentioned primary performance indicators in the ratio 1/0.5/0.7 giving travelling costs the highest impact on the objective function.
- There are several higher level performance indicators that might be used to assess different planning approaches if they tied for the KPI or even the primary performance measurements.
- The simulation model has been validated with the reality:
- In the static planning option 22% of the containers are emptied per workday which corresponds to the data provided by the Twente Milieu N.V. (appendix A 32)
- Furthermore, the static option performed in such a way that 57% average fill rate was archived per container incorporated in the system. This is based on data revealed in the work of Stellingwerff (2011).
- Given the two previous facts it can be assumed that the simulation model approaches reality with the precision needed to draw valuable conclusions on an actual improvement in comparison to the current situation and container collection method.

7 Non-computational results

In this chapter, the non-computational results will be presented and explained. Here mostly the issues that were described in the current situation of the underground container project are continued which did not need extensive computational efforts in order to conduct a solution. First of all, the focus is directed towards a possible utilization improvement with respect to the operational hours of Twente Milieu. Thereafter, recommendations for the weighing of containers, learning moments regarding the fill rates and data management will be examined. Afterwards, the issues water leakages in containers, battery performance of the container modules and an alternative routing approach in comparison to the preceding research of Stellingwerff are perused. At the end of this chapter, a container simulation is introduced in order to gain deeper insights on the actual container fill rate and a mathematical formula that intends to approximate the waste level inside of an underground container in a fairly high precision, as well as an overview on improvements of the communication flows at Twente Milieu. The chapter will be completed with a brief summary of all the solutions that will be discussed in detail below.

7.1 The Twence B.V. as operational bottleneck of Twente Milieu

It appeared to be possible to interlink the activities carried out by the Twente Milieu N.V. to the opening times of the waste-processing installation Twence in Hengelo. Since Twence is accepts refusal from 7:00 to 19:00 it would be possible to extend the collection period per workday from 6:00 (not earlier due to noise encumbrance) up to 9:00 in the evenings. As described before Twente Milieu does always empty their fleet from refusal at Twence before the quitting time – this however is not necessary, since the refusal is not dangerous to the environment when left alone at night. It could be a proposal to do another route of collection after the last Twence visit that would take place between 18:00-19:00. Moreover, Twence also accepts refusal even on Saturdays, in this respect also an extension of work time on the first part of the weekend is possible. However there is to say at this point that all of these measures only need to be taken in case of serious shortcomings according the capacity of the fleet that is needed to empty the set of containers in use. But a very interesting point is that the possession of one or even more trucks might become obsolete. As could be seen in the chapter on data analysis (financial data), it is very likely that if the Twente Milieu N.V. decides to introduce weekend work and two shifts per workday it can resell parts of its fleet to the market. The newly gained funds might be used for investment projects when on the short term a bigger amount of capital is needed.

7.2 Weighing

For a depiction see appendix A16

In order to improve the weighing procedure, it should be tried to eliminate all unnecessary actions and error sources that might contaminate the data retrieved during the weighing of a container. At the moment the driver has to manually identify a certain container and its location via a barcode list available in the trucks. Also he or she expected to always manually reset every container after the emptying has been executed. However, this includes a lot of risks for data pollution, if for example the collector forgets to offer the reset card to a container or if the scans the wrong container location or container. This also has already been described in earlier chapters.

Therefore a relatively simple solution could be to equip the containers with RFID-tags (passive) and the trucks with a RFID-reader (active) that has an approximate range of 3 to 4 meters. With this technical support the driver could focus more on his actual tasks, namely emptying the containers without worrying about too many other things that might compromise his work. The RFID applications could identify the individual containers (interaction is assumed to be low, since the truck is already around 4 meters high) and the resetting and the weighing could be automatically sent to the Welvaarts server. Based on personal experience during my field trip and the interviews that have been conducted it can be presumed that a single driver could save around 30 minutes per day on weighing and resetting. Seen a fleet of four trucks this would add to 5*30*4=600 minutes (10 hours) per work week which would be a very nice time saving opportunity. In a two-shift-Saturday-work scenario it would even reduce the time to approximately 6*(1*30+0.5*30)*4 = 1080 minutes per week (18 hours) in comparison to the current method. Thus taking difficulties out of the hands of the drivers will increase the available capacity noticeably.

7.3 Learning moments with respect to the fill rate determination

Level sensing

For a depiction of a level sensor in a container see appendix A18 and A33

Since it has been shown in the data analysis that the spread between the weight, the volume and the number of clap openings is rather big level sensing might be considered as a solution to get more insights on the actual volume inside a container. There following options are reviewed:

- Optical interface sensors:
  Referring to the literature study – and especially the research that has been carried out by Johansson et al – the possibility of optical level sensing should be considered. Unfortunately, the optical sensors can only be attached to the inside of a container horizontally, thus there are only capable to measure one certain level. So a May-Go and a Must-Go alert level should be assessed very carefully in advance, since a hardware adaption after the initial installation will be very costly. Also from an analytical point of view this type of sensors might not be that favorable because the fill process of individual containers cannot be followed very carefully in real-time. This means that if the refusal exceeded a certain threshold that has been determined as the Must-Go level it cannot be seen when the container was completely full (up the chute). In general I thing optical sensors can help to improve the insights on the actual volume, but seen it lack in measuring the continuous elevation of waste and the relatively high cost factor other level sensing option could be more interesting for Twente Milieu.

- Ultrasonic sensors:
  This type of sensors have the advantage that they can be mounted in the containers even for a continuous vertical monitoring measurement which is in my opinion outperforming the optical sensors that only measure one specific altitude of waste depending on their position in the container. Ultrasonic sensors furthermore are apparently one of the cheapest types of sensors available on the market when it comes to level sensing. B-waste already started to experiment with this kind of sensors and they seem to be promising. One big disadvantage of the ultrasonic sensors is however that the sound waves can be absorbed by porous materials like mattresses or special sorts of paper or carton. So far, however the tests conducted at B-waste showed no major disturbances that were related to absorbing material. Moreover the refusal stored in a residual waste container is rather to be very mixed and therefore it appears not that likely that total absorption of the ultrasonic waves will occur.

- Microwave / radar sensors:
  Microwave or radar sensors work relative similar to the method how ultrasonic sensors work. In contrary to the ultrasonic method, they the emitted wave are mainly reflected by metals or alloys. Plastics, glass and paper for example will be penetrated almost without any reflection. This feature and also the higher purchase and maintenance costs in comparison to ultrasonic sensors make the radar approach more unfitting to the volume determination of refusal underground containers as they are used with Twente Milieu.

In the figure of appendix A33 the application of an ultrasound sensor within an underground container is depicted. The sensor ought to be placed at a secure spot in the container where damages due to refusal deposits can be avoided or at least minimized. The position next to the maintenance door seems to be a perfect fit for that purpose.

Categorisation possibilities

See appendix A19 for more information.

To test a possible sensor application a certain number of approximately 20 containers should be picked as test containers in order to see whether level sensing is working well and if the results improve the analysis of the fill process. The proposed test containers ought to be selected as different as possible to research various scenarios.

7.4 Data base management

To improve the analytical capabilities of the container filling it would be advisable to transfer all the data from the Mic-o-Data database to the B-waste database. A single database would have clear advantages above the two database option that is handles contemporarily:

- Pitfalls and failures in the system become visible earlier
- Less maintenance efforts
- More feature available for more containers, since the B-waste database is more sophisticated in comparison to the old Mic-o-Data one.

7.5 Water leakages in containers

In order to tackle the issue of the water leakages in the pits of some of the containers it would be useful to check the isolation of the concerning pits and in case of continuous failures due to this error the isolation should be replaced.

B-waste is able nowadays to add also water sensors to the controlling module of the containers. This might be an option to consider for Twente Milieu, if the water leakage problem extents. Especially the containers with frequent water issues could be equipped with this kind of sensors.
The container placing procedure ought to be reviewed in order to discover mistakes in the replacement set-up approach. Doing this can decrease the failure rate due to water leakages of the containers that will be placed in the future.

Review container placement procedure and methodology in order to remove design causes of that error

7.6 Battery performance

According the battery performance it seems to be advisable to contact the supplier with respect to this issue. At that time also the idea of photovoltaic containers ought to be discussed. A picture of such a photovoltaic container can be found in appendix A20. The advantages of such a type of container are clear: less maintenance and a higher environmental friendliness which is pursued by the Twente Milieu N.V. Besides also it can be looked for an enhanced battery composition with a longer life time.

7.8 Alternative routing approach: "zones method"

In addition to the routing approaches designed in Stellingswerff's work – that has been predeceasing to this research - I created a different routing approach that might overcome various difficulties of other approaches due to a zone-selection and extension focus when must-go and may-go jobs are selected. Mainly the approach is based on the cluster first, route second algorithm Gillet and Miller (1974), but it has been modified to fit the environment of the Twente Milieu N.V.

The methodology of this method works as follows (see flowchart "zones method" in appendix A2, A3):
Initially the number of available trucks that can be used for a schedule has to be inputted. When this number is known the trucks can be distributed among the most urgent zones that include the highest number of must-go jobs. Thereafter, primary sub-zones are selected around these zones, again based on the highest number of must-go jobs and they are set on "active". If any very urgent emergency job – meaning that a container will overflow today – is located in one of the neighbouring zones of the first active zone of a truck, the zone they are in will as well be set on "active". Only the neighbouring zones of the initial zone that contain must-go jobs are allowed to become active in order to decrease the spread of a possible route later on. If a zone does not consist of must-go jobs it will not be able to become active. Mainly it is thus looked for the must-go jobs, however if all the must-go jobs of the active zones are included and the truck capacity is still not reached, it is also allowed to include the most favourable may-go jobs in the routing – which is based on nearest insertion. The size and the number of the zones are vital for the success of this approach and needs further investigation. Choosing too few and large zones might give too much spread in the routing, while choosing to many small zones might increase the possibility of not reaching all the emergency jobs that really have to be dealt with. A trade-off for this issue has to be found.

7.9 Container simulation (5m³) & waste volume determination

In the figure in appendix A15 the execution of a test with a paper model of a $5m^3$ container is depicted. At the top the model blueprint is shown. The picture sections 1 to 6 visualize chosen fill moments during an experimental run. These fill moments were later on used to approximate a realistic fill pattern, in order to make the volume of waste more predictable by using a top angle altitude level measurement. Especially, pictures 8 and 9 show the characteristic pyramid-like shape when a container is filled up to its feed chute. In addition, the paper model was aimed to create deeper insights in the number of trash bags used and its resulting variation and to determine the total amount of loss in capacity of the $5m^3$, since the upper corners below the container cover cannot be used for storage. The current assumption of Twente Milieu is a 10% loss; however, reality seems to differ.
The experimental set-up and the calculation overview can be found in appendix A31.

Experimental design and general comments

As could be read in chapter 2, the capacity of the containers used assumed by Twente Milieu is under the suspicion to be not entirely accurate. This suspicion led to the following experiment that is depicted on the page before. In general, it would have been more favorable to conduct such a capacity experiment with a real sized underground container, filling it up with actual waste bags. However, this kind of experimental setup could not be executed within the frame of bachelor internship at Twente Milieu and therefore a paper-model-based experiment has been chosen. The basic shapes of this paper model can be found in a 1:1 ratio in appendix A15 if there is a need to collect more samples with this set up. The paper model is a 1:10.4 representation of a 5m³ underground container currently used by Twente Milieu. The waste bags were simulated with paper balls that were varying in size between ca. 3 and 4 cm. The main shortcoming of the experimental design used is the fact that the true density of real waste bags could not be accurately simulated – consequently also a possible upset factor that is very likely to be observable in reality could not be researched on. Besides the paper container is not as strongly build as its metal equivalent, thus deformation of the container walls might also have influenced the outcomes for the experiments. It was aimed to conduct the following data from the trails described:

- Altitude of the paper waste bags towards the top cover before shaking, measured at the container side with the longest distance to the hatch (in order to verify the fill pattern later on)
- Altitude of the paper waste bags towards the top cover after shaking (in order to approximate the loss in volume)
- The amount of paper waste bags used (in order to make assumptions according to the variability the takes place in the fill process)

With the information about these three parameters of the fill process a 90% respectively 95% confidence level was ought to be calculated under the assumption that the deviation in the altitudes and numbers of bag is based on a bell-shaped Gauss-curve. Moreover, it was another goal of these experiments to find out whether a high variation in the paper waste bags is like to occur and which pattern is most fitting to create a fill process model enabling relatively accurate volume determination in practice with only a one-point level measurement.

Measurement system and procedure

The container model has been filled up with the previously described paper waste bag for n=20 repetitions. Each time the model was filled the order of the paper waste bags has been randomized in order to introduce a higher variation in the pattern building during the fill process. A single filling run was considered to be completed when the paper balls reached the hatch of the top cover – as can be seen in picture 7 on the previous page. The paper balls have been hold straight upon the feed chute and fell inside the container model without touching the frame of the lid in order to avoid a more evenly spread waste level that would have been unrealistic in practice. The tolerance of this process was around a maximum 5 mm for overcapacity, meaning that if a paper waste bag was sticking out of the lid for more than 5 mm this particular paper ball was not counted for the experimental results. Moreover, the minimum fill was around 5mm below the lid. This implies that if the fill reached up on this level the run was stopped. After the fill was completed the number of paper waste bags was written done and the first measurement of the straight line on the container wall with the longest distance to the lid was performed. Here the measurements might even have a higher inaccuracy since the waste level was normally not straight in most of the case. Thereafter, the container model was shacked for several seconds, so that the top of the waste pyramid that has formed during the fill was smoothened out to a (relatively) even surface. Doing this none of the paper balls have been added, removed or replaced to assure that the resulting (even) fill level only resulted from the currently used paper waste bags. Finally, the third data issue could be determined: the altitude of the waste towards the cover of the container. This measurement, after the exact amount of paper balls used, is the second most accurate measurement of this experiment with a relatively low tolerance level.

Of course also the shortcomings of the used measurement system should be considered in this section, since the variation measured can be split up into two main causes: $\sigma^2_{experiment} = \sigma^2_{actual\ (waste\text{-}bags\text{-}based)} + \sigma^2_{measurement\ system}$ One part of the variation derives from the actual process difference and another from the measurement system itself. In this situation, the resolution of the measurement was not that high; therefore, out of personal assessment a tolerance of ±5mm appears to be fitting. Taking this into account the outcomes might differ up to 100*(5+5)/240≈ 4.2% in comparison to the determined ones.

Results

All in all, the results gained through this simple experiment were quite interesting, since they confirmed the suspicion that the assumption of a 10% capacity loss per container due to a pyramid-like fill process is not entirely correct. As can be reviewed in the tables in appendix A31 with a confidence of 90%%, it can be said that the loss in capacity of a 5m³ container is about 22 to 23% of its original volume. That is more than double the loss that has been assumed so far. Even taken the variance of the measurement system and the wider 95% confidence level into consideration, a minimum of at least ca. 17.4% of the original capacity of a 5m³ container is lost, because of the pyramid-like fill pattern. In conclusion, Twente Milieu should calculate the loss with about 20 to 22%.

Furthermore, with a 90% confidence it can be said that the number of paper waste bags used to fill the container were between 88.3 and 131.3 – thus a variation of approximately 43 paper waste bags is possible taking a 10% misinterpretation change into account. That is a rather huge amount, since almost only the accumulation pattern of the paper balls is responsible for this outcome. Even though this experiment still has to be verified in with an experiment with real underground containers in practice, this insight is clearly an indicator that a fill rate determination only based on the number of disposals is not a very reliable way to predict to volume of refusal that is supposed to be collected.

The fill pattern (left sub-figure on the next page) that could be observed is depicted in the figure on the left. Throughout the picture sections 1 to 6 in appendix A15, the reader can comprehend why the fill pattern has been assumed like it is show here. At the beginning the paper balls almost evenly spread on the ground of the underground container due to spring effects. However, this effect fades during further filling, so that underneath the feed chute an elevation accumulates. This goes on until the top of the containers is reached under a continuous increase of the steepness of the waste accumulation. Since the paper balls, as well as real waste bags are not very pointy the top of this growing pyramid inside the container can be assumed to be flat with the size of approximately the feed chute. Further explanation of these assumptions will be given in the section “Waste volume determination”. However, for a confirmation of these findings a test on a real underground container should be performed before a dynamic routing implementation.

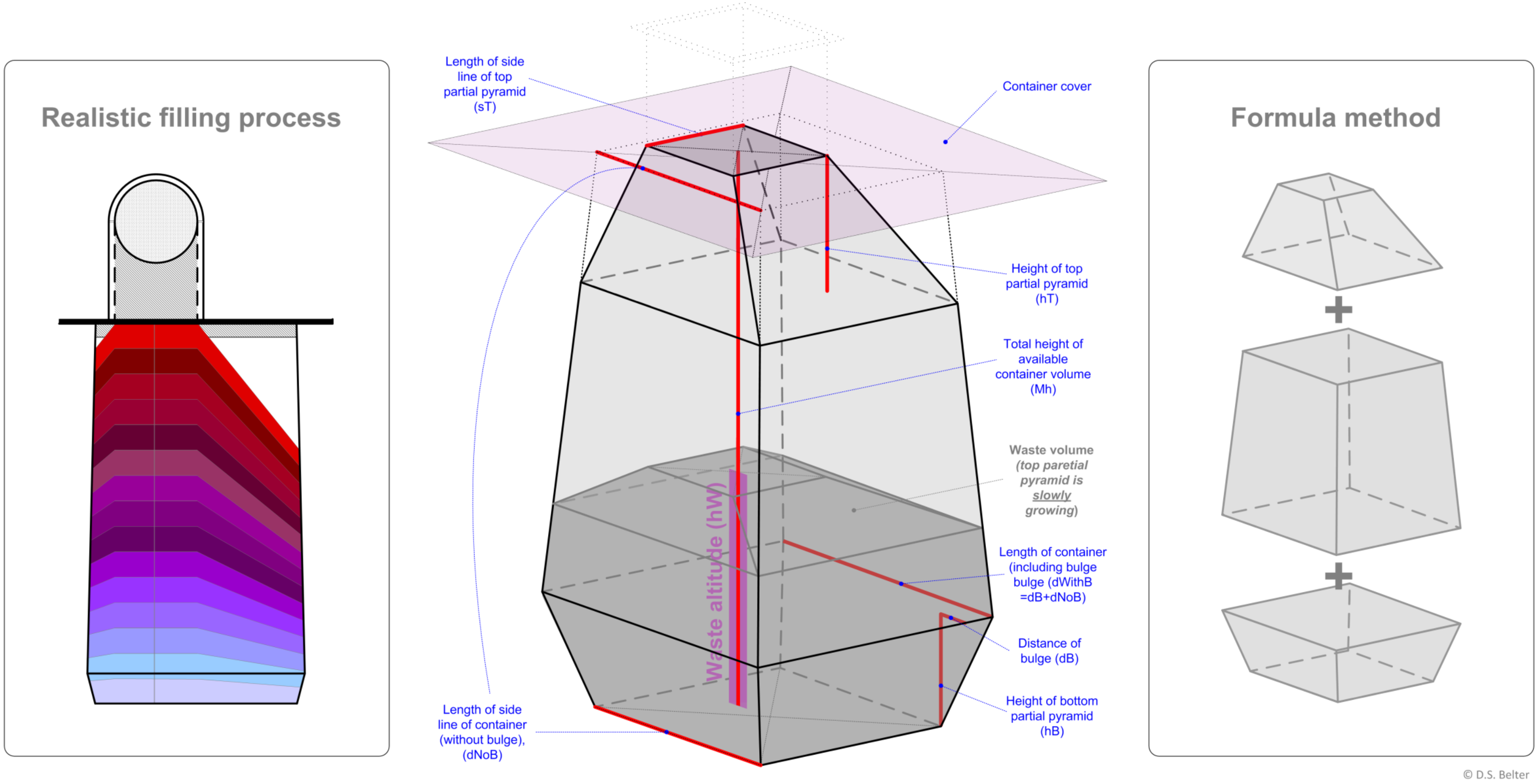
For further explanation and formulas see appendix A28.

It already has been pointed out in earlier chapters, that there is a need to determine the exact amount of deposited waste within a container in a relatively accurate manner. Therefore, a formula has been designed (appendix A8) that determines the volume of waste in a container based on basically one single non-fixed parameter: the altitude of waste in relation to the top cover of the container body (see figure below). To measure this distance, a level sensor will be needed, since it already has been shown that guessing of the volume based on the clap openings alone is an insufficient indicator for the true amount of waste deposited (Chapter “Data Analysis”). This particular sensor has to be placed near the lid (in a secure position, as depicted appendix A33) in order to be focused on the top of the waste elevation that is growing with every deposit.

The mathematical formulation of the volume determination is examined in the appendix A28. The basic principle is rather simple: the volume is calculated by adding up three different partial pyramids that develop continously during the fill process due to the container shape of the containers used by Twente Milieu (see below figure) and the pyramid-like fill behaviour of the refusal (similar to a sand fill).

There are several changeable parameters included in the formula so that the volume determination can also be applied for $4m^3$ or $3m^3$ containers (see figure below). A list with a certain volume in m³, given the altitude of waste, also can be found in appendix A28.

Changeable parameters for waste volume determination formula



7.10 Communication flows at Twente Milieu

Good communication and the related information exchange are essential for a wide knowledge structure within a company, so it is for Twente Milieu. During my internship at Twente Milieu some issues with regards to data mining came to my attention and will be elaborated on in the following two sections: "personnel and informal communication" and "central information points".

Personnel and informal communication

In general it appeared that information is often exchanged orally only which has as a consequence that every now and then essential pieces of data get lost in during the operations. Furthermore, many assumptions are considered to be the true, while the date of assessing these assumptions might lie a long time ago in the past. Therefore, a periodical review on the assumptions used and a general critical attitude towards assumptions that are considered to be facts are very important and should be communicated.

Central information points

To help the above mentioned development towards a critical attitude about presumed truths central information points are needed in order to access and assess data rather quickly with regards to their relevance and correctness for several issues. In this context, also the use of the two databases supplied by Mic-o-Data and B-waste is rather unfavourable, since the information retrieved from these databases is often different in its compilation. My personal opinion would be to integrate the two databases as fast as possible into the B-waste environment, since B-waste is the current supplier of the containers and the guarantee period for the Mic-o-Data containers has already passed, so it did for the former database.

Moreover, it appeared that there is a strong need from the maintenance department to have up-to-data container information in order to reduce the repair times significantly. At the moment a repair team does not know the features of a container until they are at place. This problem could be tackled by giving the maintenance operators modification access to the container feature database, so that they are able to update the necessary entries by themselves instead of purely administrative co-workers.

All in all, better housekeeping and an extension in content and user friendliness according to the used databases has high potential to increase the performance of the Twente Milieu N.V. in general.

7.11 Summary non-computational results

In this section the results that have been presented in detail beforehand are again summarized in a compressed form.

- Integration of the Mic-o-Data database into the B-waste database.
- Water leakages can be dealt with:
  - Revising the placing procedure of underground containers
  - Preventive isolation checks
  - Water sensors added to the existing control modules
- True capacity of 5m³ containers is approximately 4m³ because of losses in capacity due to a pyramid-like fill process. (see chapter "Data Analysis")
- A formula has been developed to determine that volume of the waste based on the altitude of the refusal inside a container (see appendix A28)
- An alternative selection and routing method based on planning clustering first, routing second can be taken into consideration before actual implementation of dynamic waste collection.
- Shifts can work to increase the capacity in the collection process
- Taking the opening times of the Twence installation as bottleneck of the operation of the Twente Milieu N.V. can improve the capacity of the waste collection
- RFID applications can be used to decrease data pollution and to avoid manual resetting of the containers which also would result in a slightly higher working capacity, since the resetting actions can be cancelled out of the operation. Furthermore automated container identification would become possible with low efforts (see appendix A16)

8 Computational Results

The following chapter is about the computational results that could be obtained during the simulation study of the Twente Milieu case. At the beginning, the chapter in initiated by a general summary of the happenings and results that came to attention during the simulation phase. Within section 8.1, the majority of the computational results are gathered and explained in detail. First, it is started with the exploration phase throughout the various policies; thereafter a look is taken on the comparison of the policies among each other. And at the end the improvements and savings of the best dynamic options towards the static default option will be analysed. All the important findings will of course again be summarized at the end of this report unit.

8.1 Summary statistics in general & the exploration phase

In this section of the report, the focus is directed towards the computational results that could be conducted with the simulation model described in earlier chapters. In the current simulation, first the factor of the rescheduling options was researched on; thereafter the horizon of the Must Go days and later the one of the May Go days was up to adaption. Subsequently, the balancing option (with MaxBalancing = false) was tested, as well as a planning method that works with a fixed amount of Must-Go and MayGo jobs. In addition to that, also combinations of the factors mentioned above were researched on.

The Static planning approach is the first one to be reviewed in detail, and then the several dynamic options follow with an analysis of the simulation outcomes. At the end, all of the available planning options are compared with each other based on several types of variation and uncertainty that have been introduced in the chapter "Simulation model set-up". These variations are deviations in the deposits according to sinus, uniform, standard deviation, mean and estimation of the mean uncertainty.

8.1.1 Static Planning

For graphs see appendix A21.

The static planning option was build in the simulation model in order to give a reference point in comparison with the tested dynamic options later on, in order to benchmark as realistic as possible.

First of all, the rescheduling options were tested in the static method to see whether they might have a significant effect on the performance of the collection process. In the appendix A21, three figures are shown that are related to the rescheduling under several types of uncertainty that could occur in reality, according the data analysis phase. Rescheduling option 2 (only reschedule the truck that has a capacity problem) appears to be the most beneficial in all of the case, however under an uncertainty in standard deviation of the deposal mean the effects of the different options seem not to vary a lot. In general, the re-planning options are not that influential on the results due to the fact that the static policy uses relatively accurate insights on the fill level of containers. Therefore, the static routing can be adapted in more detail which leads to an enhanced schedule and also unnecessary rescheduling will be avoided. For the other rescheduling options (except number 2), it is to say, that their effect on the outcome is rather unfavorable. A reason for that can be that the trucks in the simulation have a target capacity of 85000L while their true capacity is 90,000L. When rescheduling takes place with only the truck that has trouble, it is taken into account for rescheduling of the other trucks, that they might make use of the slack in capacity. Thus, if the slack in capacity is null, the other options might reveal their true potential – this is studied on later in this chapter. For verification purposes also the results of a varying StaticMax were measured (maximum percentage of containers emptied during one work day). The minimum is reached at 1 which is the default of the simulation, thus emptying at a 22% level gives the best results in a static set up. If less containers are emptied the penalty costs increase, if more are emptied then strictly necessary the transportations costs will show their impact on the higher total costs. This is a good sign that the standard setting of 22% emptyings per day are the optimum for the static policy and also it corresponds to the operational facts provided by the Twente Milieu N.V. Furthermore, another experiment with regards to a deviation in the mean of the deposits was conducted. Apparently, it is more beneficial if the deposits are a little bit overestimated to reach the minimum in the total costs. This is due to the chosen penalty costs of 0.7. If these costs would be estimated higher the minimum would approach 1, however, in relation to the transportation costs, 0.7 for the penalties seemed fair, since we strive most to reduce the amount of kilometers driven and secondly to for a high customer satisfaction.

Moreover, in the 700 container case it is very visible that sensors have a positive effect on the performance of the system.

8.1.2 Dynamic Planning – Normal

For graphs see appendix A22

Now we look at the first dynamic and simplest planning option of its kind. As can be seen, three different types of experiments have been conducted to generate more knowledge about this planning method. At first the experimental setup tried to bring the horizon for the must go day to light. This was done again under various types of uncertainties which have been described in the chapter "Simulation set up". Thereafter, all of the rescheduling options were reviewed once more and also the sensitivity of mean of the deposits and estimation errors has been researched.

First of all, we take a look at the horizon for the Must Go Days (this is representing the actual deadline when a container really needs to be collected. Seen the figures in the appendix A22, it appears that it works the best if the Must-Go day is chosen not too large and not too small as well. With a Must Go Day of 0 for example, it is very likely that the collection always takes place just too late, since a Must-Go day of 0 indicates that only those containers are emptied that are full during the current day. Thus, a container has a high probability to already overflow during the day, so that the penalty cost are likely to increase to a great extent. On the other hand, a Must-Go day of 3 is responsible for too much unnecessary emptyings; and therefore also the travel costs will be much higher. In general, it seems that a Must-Go day of 1 or 2 is considerably better than a very short or a rather long Must-Go horizon. At this moment, it cannot be concluded precisely which option is strictly better. But for many situations it can be assumed that the closer the horizon is to the trade-off between transportation and penalty costs the better the results will be. At the moment (with this policy) a Must-Go day of 2 is more likely to be close to that edge than a Must Go day of 1 or 3.

According the rescheduling options, again it is to see that the effect of other rescheduling options than the rescheduling of a single truck with a problem appears to be non-value-adding under most circumstances. However, the sensor information has much more influence now, since that information is also used in the simulation to determine a better selection of a container set that has to be emptied.

With respect to the experiments that are related to variation of the mean of the deposits, it simply can be seen that the higher the mean is the higher the transport costs as well as the penalty costs increase. In contrary, only the transportation costs increase when the mean decreases, since it is travelled too much for too few waste. This observation could already be viewed under the static option and has the same reasons as explained in the section before.

The estimation error with respect to the mean shows some interesting development when the deposal amount is expected much lower than it is in reality. In that case, the penalty costs explode. However, a very optimistic estimation of the refusal amount does not have a lot of influence on the travel costs. This is mainly due to the very strict focus on Must-Go jobs only, underestimating results in delayed emptying, while an overestimation causes more travelling, since more Must-Go jobs are collected – actually now these jobs are almost at the same level as May-Go jobs in later policies.

Regarding the number of emptying the picture looks as follows:

Monday	Tuesday	Wednesday	Thursday	Friday	Average	σ
72,8	38,2	42,2	45,8	111,2	62,04	30,65205

In total, this is a lower amount of collections than with the static planning, but the variation of the emptying per day is rather big. Moreover, the collection pattern above approaches the StaticMax=0.6 of the static option, which was also a local minimum (see graph in appendix A22). As for the variation in the mean and the estimation error the same results are observable like with the static planning. One fact is very interesting to notice; the Dynamic Normal method seems to work better than the static one (since it is most of the time at least 1 cent cheaper according the total costs per liter), besides that with the application of sensors again the performance can be improved visibly.

8.1.3 Dynamic Planning with Balancing

For graphs see appendix A23

The dynamic planning option with balancing has been tested on the same criteria like the normal dynamic method.

In regards to the determination of a fitting Must Go Day, the result of the dynamic option with balancing appears very similar to the dynamic normal one – with the exception for a Must Go Day of 0 and 3. A Must Go Day of 0 works better now within situations those have more stability in demand. But still both extremes are not very well performing in comparison to a "smoother" Must Go Day of 1 or 2.

In general, it is to observe that the different rescheduling methods of the balancing option are not performing incredibly better with reference to the regular dynamic planning. This is assumed to be mainly due to the overcapacity of two operating trucks for 378 containers. On Fridays, there is enough capacity left to fulfill a higher number of emptyings, however, when this is not the case anymore, the circumstances might change and rescheduling more often and on several trucks simultaneously could help.

As for the mean variations of the deposits, the picture almost is equivalent to the normal dynamic option; however, a slight increase of the total costs is visible, when the mean is shifting towards the right side of the x-axis (increasing mean). The collection pattern throughout a work week looks as follows:

Monday	Tuesday	Wednesday	Thursday	Friday	Average	σ
48,39167	38,98333	58,075	87,03333	99,19167	66,335	25,72103

The number of emptyings is higher than in the situation without balancing – which is of course since more collections are done in advance to avoid a high workload at the end and the beginning of a new workweek. Now the work content is spread more evenly throughout the week. The peaks of the Fridays and Mondays have been pulled towards the middle of the week. The standard deviation of jobs done during a workday has obviously decreased, but it is still relatively high, since Mondays and Tuesdays are not balanced - this happens further on in a week (e.g. Thursday and Friday). On Tuesdays, it is collected less because most of the emptyings already took place on Monday.

8.1.4 Dynamic Planning with MayGo jobs

For graphs see appendix A24.

As for the determination of the fitting Must-Go day, it became visible that a high value for either Must-Go days or May-Go days is working out better in situations with high uncertainty – and of course less with low uncertainty. In general, it seems that the combination Must-Go day 1 & May-Go day 3 is performing the best overall. However, as default the combination Must-Go day 1 & May-Go day 5 is chosen (which is also the default of the dynamic MayGoFixed policy), since in the 700 container scenario it showed the best results, too. For Dynamic MayGo the May-Go day of 5 is performing worse since the number of total jobs is not constraint and so it is more travelled than needed (in the simulated scenario it can be spoken about overcapacity).

Studying the effect of sensors, it shows that the combination Must-Go day 1 & May-Go day 1 has the some benefits from the sensor information, however, mostly with high uncertainties of any kind. In stable situations, it is emptied more than needed anyways, so the costs are lower or equal to the option with the additional sensor data. For the combination Must-Go day 1 & May-Go day 5 the beneficial effect of sensors is even increasing.

With regards to the rescheduling options, again it appears that more frequent rescheduling does not give tremendous added value. One important observation is that the costs even increase rather a lot the more rescheduling is applied. On one hand the penalty costs decrease, but on the other hand the travel costs seem to explode. It could be that the target capacity of 85000L per truck – and its incorporated slack of 5,000L - is the reason for this phenomenon. This will be discussed in a latter section of this chapter again.

The mean variation for the dynamic MayGo policy shows that it is more beneficial if there is an unexpected rise in demand for this policy, since then the number of May-Go jobs is unlimited. This seems to have a positive effect on the penalty costs while the transportation costs appear stable. Thus, a constraint upon the number of allowed jobs per day could help to solve this issue for the default as well. Again, with the estimation error it can be seen that a strong underestimation of the mean results in most cost savings, which actually should not be the case.

8.1.5 Dynamic Planning with fixed amount of Must- and MayGo-jobs

For graphs see appendix A25.

The best option, with regards to the relation of Must-Go and May-Go day, under all types of uncertainty is the combination of Must-Go day 1 & May-Go day 5. The choice to select a rather small value for the Must-Go day helps to ensure that the focus in aimed towards only the most necessary jobs. On the other hand, a large May-Go day value gives much more freedom in the containers selection – which then is constraint from the top by the maximum workload allowed per day (default 22% of the container population per day as a maximum).

Sensor information seems to gives fewer added value to the performance of this policy, since the capacity that is available with two trucks for 378 containers is more than enough to cope with the demand in Must-Go and also May-Go jobs. In the 700 container case, the sensor information, however, has positive effect on the results and therefore should not be underrated.

As for the evaluation of the rescheduling options, it becomes again visible that re-planning more often does not improve upon rescheduling only the truck which has a problem. The reasons for this effect have been elaborated on in the previous sections (capacity slack).

The dynamic MayGoFixed policy has its optimum in total costs per collected liter refusal in the cases of a mean-, estimation- and a StaticMax-variation around a value of 1. This is a very good sign, indicating that the policy is working well with the default StaticMax (maximum workload) of 22% of all the containers in use).

Moreover, it can be seen that the handlings costs are elevating for an increase in the estimation error (Expec) while the penalty costs decrease simultaneously. This is due to the higher collection frequency that is involved. The transport costs stay low near the default of the Expec-deviation. Apparently, first the policy seeks for other containers which do not need additional travelling in vast extents (probably another container of the same multi-container location is chosen as May-Go). However, later on the transport costs increase as actually initially expected.

When the mean is increasing, all of the costs (travel, handling and penalty) are rising – as expected. However, since more liters are collected the costs diminish in the beginning (overcapacity advantage). Only later on when the two trucks are reaching their capacity limits the costs per liter increase tremendously.

As for the experiments with the allowed workload per day (StaticMax), the costs stay relatively stable with a small increase when the StaticMax does up – the rise in transport and handling costs is compensated meanly with a shrink in penalties, so the increase is not that dramatic. A very satisfying observation is that the total costs reach their minimum at about 1, meaning that the policy works as intended at the default of 22% total workload per day.

8.1.6 Dynamic Planning with Balancing and MayGo-jobs

For graphs see appendix A26

The Dynamic planning policy that included balancing and May-Go's is rather unremarkable in its performance – in a negative way. Almost all the deviations show similar costs at all levels. It seems that Balancing and May-Go's are cancelling out the initially positive effect they had. Also, there is a high overcapacity in the 378 container scenario (with two trucks) which also is a reason that probably all the jobs can be done on time even without balancing.

As for the mean and estimation error experiments, the graphs look very similar to the ones of the dynamic MayGo option and have the same behavioral reasoning as explained before. In general, this policy, however, does not seem to work well at all.

8.1.7 Dynamic Planning with Balancing & fixed amount of Must and MayGo-jobs

For graphs see appendix A27

As already seen in the sections above, a lower value for the Must-Go day is more beneficial for the system performance. Now however, the effect of sensors is very much noticeable. For the rest, the graphs are rather similar to the ones of the dynamic MayGoFixed policy.

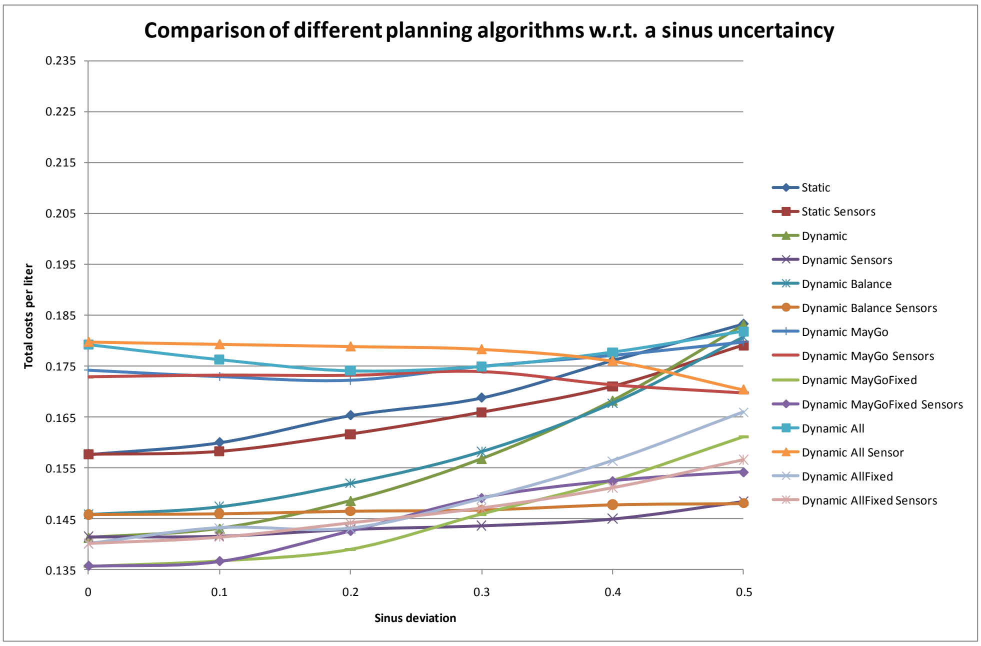
General remarks

The factor "shifts" and "weekdays" has not been examined in the simulation study, since relatively early it emerged that an increase of the time that can be worked during a day is in every case a capacity increase which will lead to a higher performance rate – as defined in chapter "Current Situation".

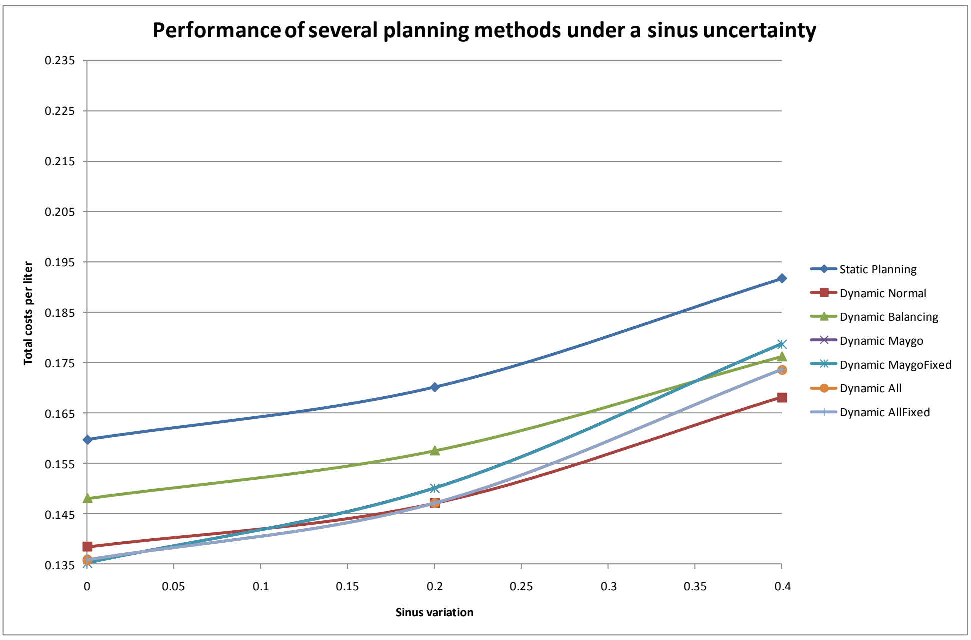
8.2 Method comparison / mutual benchmark

Now in this section the previously examined planning methodologies are compared against each other according the three types of uncertainty used in the simulation model: sinus, uniform and standard deviation, as well as their performance if the demand is overrated or if the mean of the demand shifts drastically.

378 containers – Sinus variation



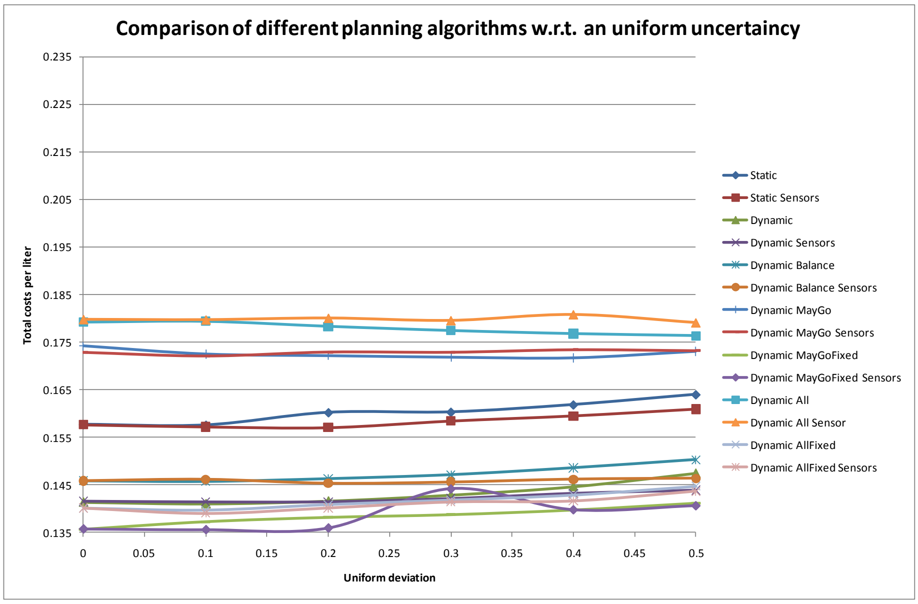
700 containers – Sinus variation



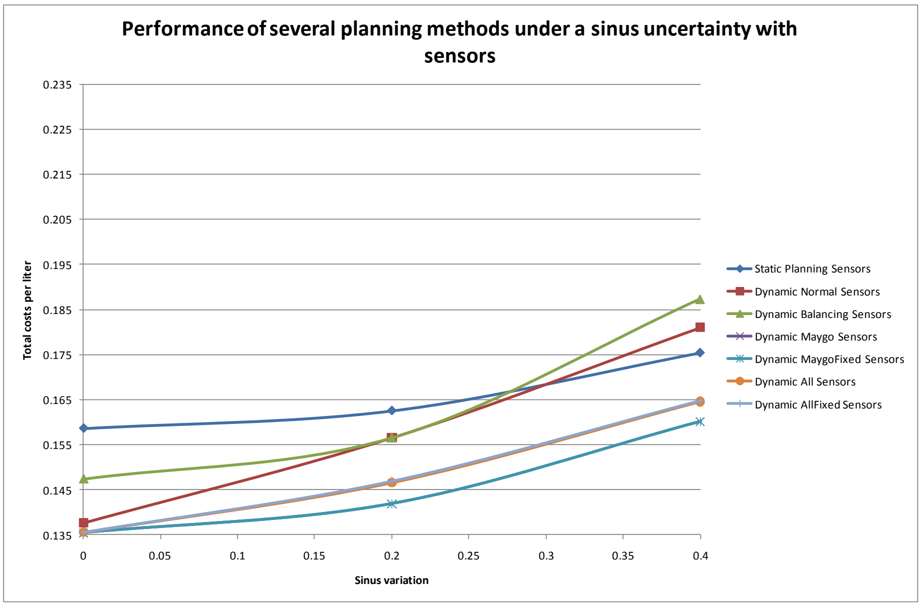
Sinus variation plays a major role with regards to the variation that can be observed. The policies dynamic normal with sensors (at high sinus fluctuation) and Dynamic MayGo(Fixed) with sensors perform the very well. The best option according to the performance under a sinus variation in the demand up to 0.3 can considered to be Dynamic MayGo, while Dynamic Normal with sensors takes the lead after a sinus variation of +0.3 multiples of the mean. It can be assumed that the Dynamic MayGoFixed option has a problem with higher sinus fluctuation, because in contrary to the uniform deviation, the mean in the sinus-curve stays higher or lower for a longer period in time – in this manner shortcoming cannot be “repaired” easily on a day-to-day basis. Thereafter the options Dynamic Balance and Dynamic Normal follow as third best and fourth best policy.

The sinus variation leads to the following observations; in particular, the dynamic policies MayGoFixed (with and without sensor accuracy) are not extremely capable of dealing with situations that have to incorporate a lot of wave-like periodic uncertainties. However, also their results in instable situations are not far away from the optimal of other policies. It is to keep in mind, as could be read in the chapter of the data analysis; the environment where Twente Milieu is operating in has a sinus-like kind of uncertainty in the deposits per week and weekday.

378 containers – Uniform variation

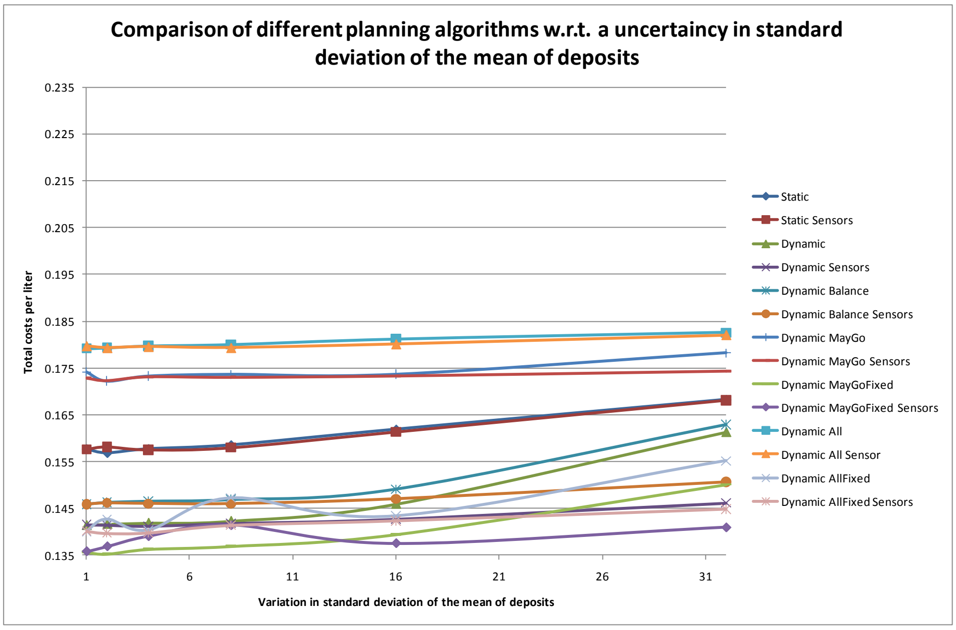


700 containers –Uniform variation



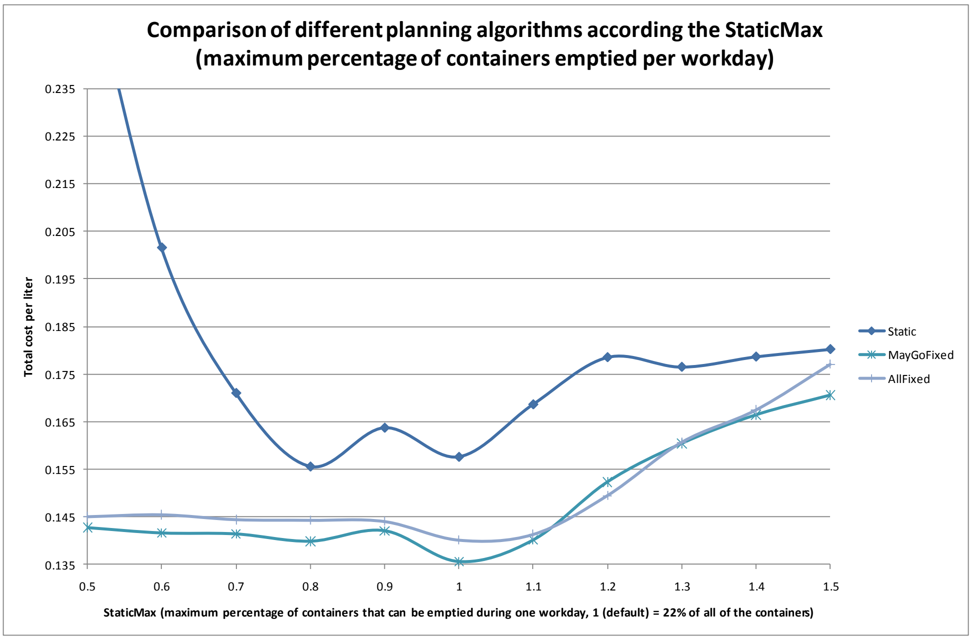
With regards to a uniform variation of the mean value per day, really bad policies are Dynamic All with sensors, Dynamic All, Dynamic MayGo with sensors and Dynamic MayGo. The reason why these policies appear to work that inefficiently is to seek in the way they deal with overcapacity. As mentioned before, normally schedules are just filled up with MayGo jobs and it is driven much more than strictly required. All options that constrain the overcapacity are doing well – especially dynamic MayGoFixed shows very good results.

378 containers –Variation in standard variation



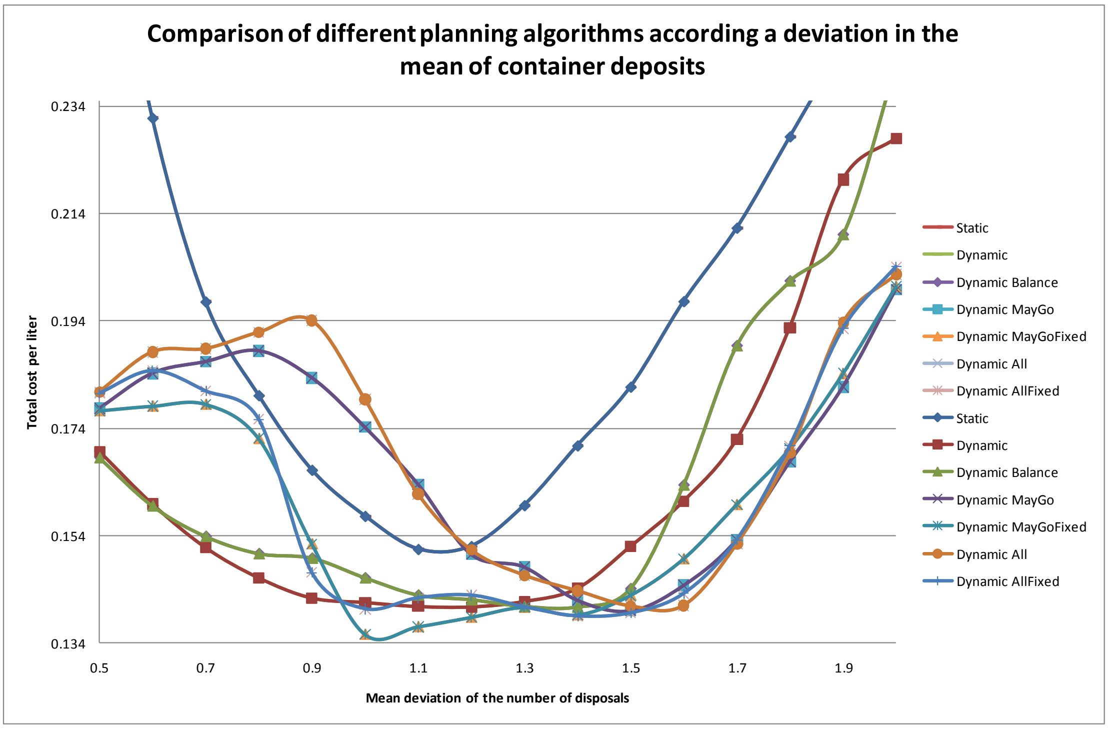
The variation in the standard deviation of the mean causes similar policy behavior like with the uniform variation. The usage of sensors now even seems to give higher improvements upon the options that do not use sensor information for the fill rate determination. This was expected, since the uncertainty is rather big now (up to 16 or even 32 times the default standard deviation – which in reality most likely never will occur). All the best performing policies rely on sensor information. Dynamic MayGoFixed with and without sensor usage are doing fine with this type of uncertainty.

378 containers –Variation in allowed workload per day

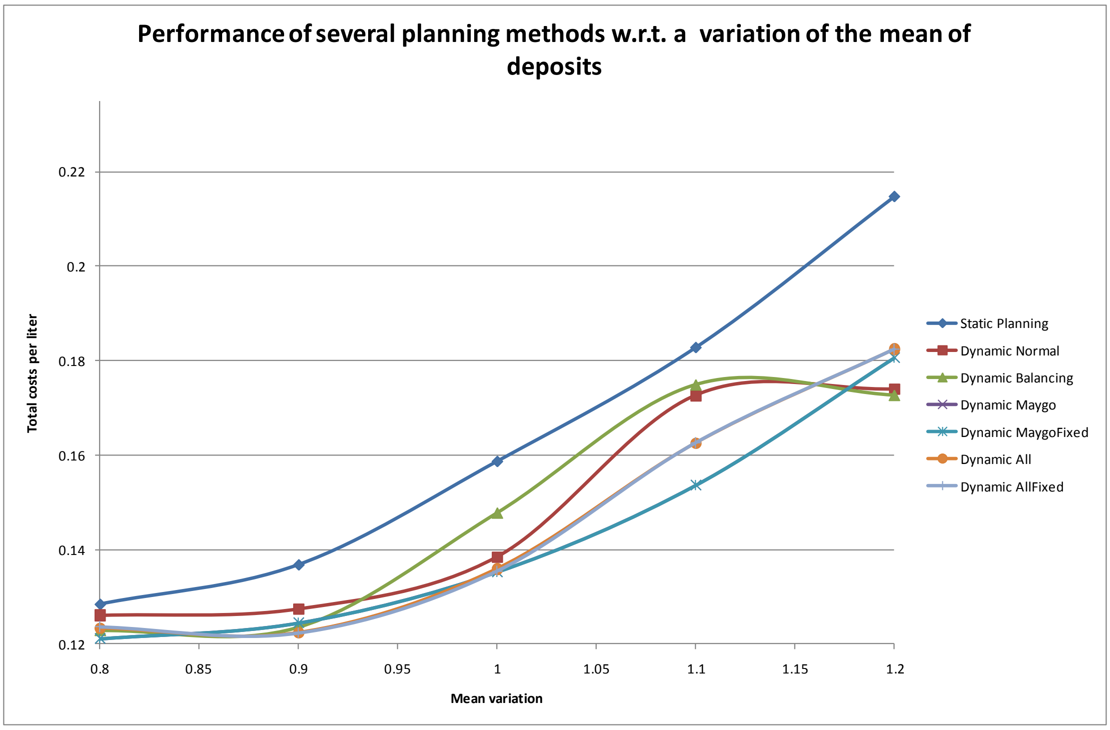


It is visible that the minimum amount of total costs per liter lies around 22% containers emptied of the entire container population for both the static and the dynamic approach (StaticMax comparison) – which is good, since both policies perform the best at the default scenario as indented. The dynamic MayGoFixed option seemed to works the best in comparison to all the other dynamic policies.

378 containers – Deposit mean variation

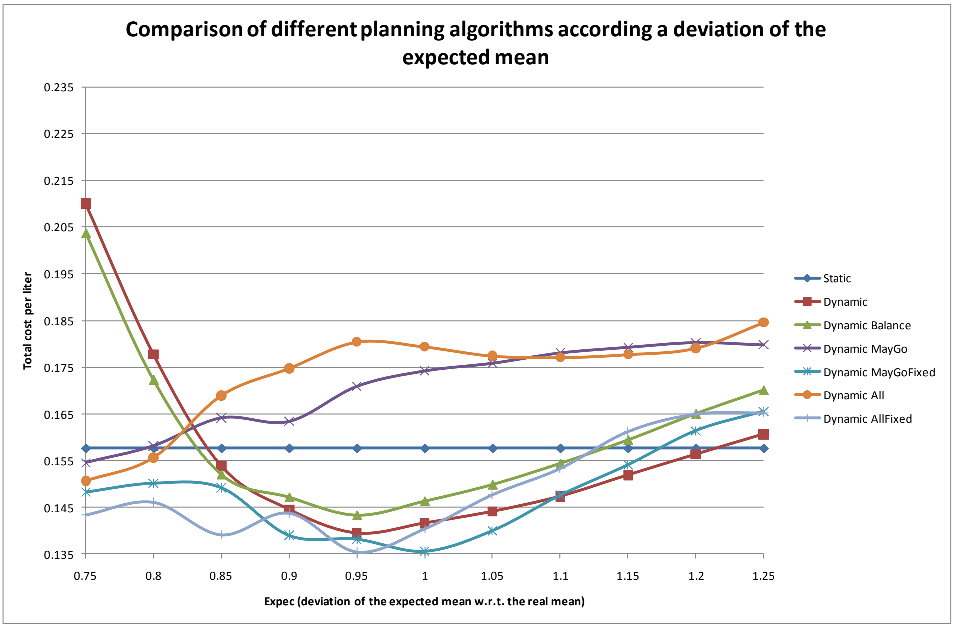


700 containers – Deposit mean variation

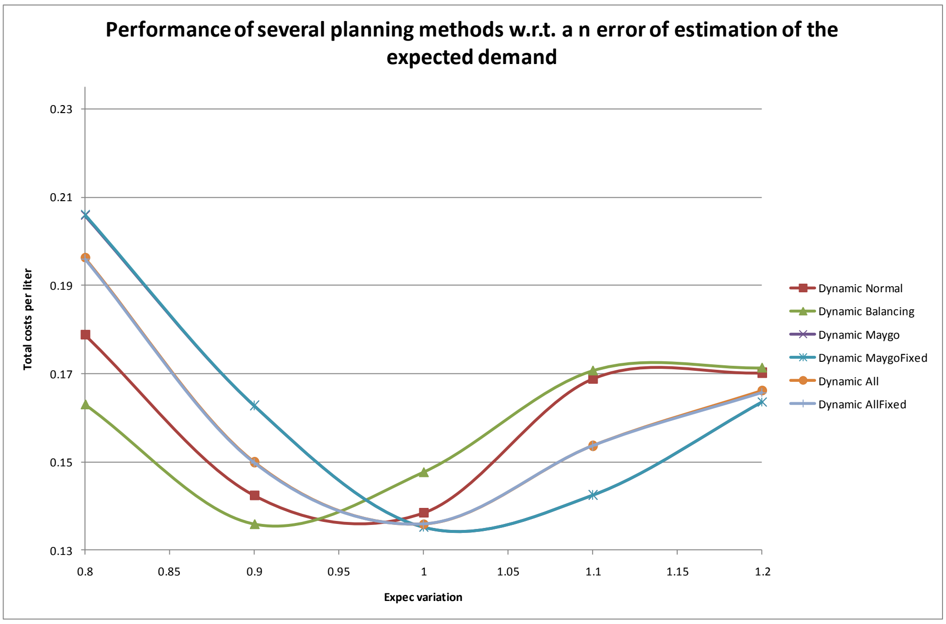


Regarding the mean deviation, the static option has its minimum around a value of 1. The dynamic policies that do not work with the a constraint in total workload per day (dynamic Normal, May-Go, Balancing and All) show a optimum to the right of the default mean value, meaning that in general they seem to collect more than needed. When the mean increases, the costs per volume decrease and therefore a higher mean works in favor. The policies May-Go and All work relatively bad around the default mean. Overcapacity is not constraint within these policies so it seems that that additional work capacity is filled up by collecting more than necessary through which the transport and handling costs increase a lot. The dynamic normal and the dynamic MayGoFixed policies seem to perform the best in the mean variation scenario, since the focus is laid mainly on the Must-Go jobs. In stabile systems where there is deposited more than usual, the dynamic normal option works quite well. However, in instable systems (with a high sinus or uniform deviation of the mean) the dynamic normal option shows some shortcomings - in contrast to dynamic MayGoFixed.

378 containers –Variation in the expectation of the mean of deposits



700 containers –Variation in the expectation of the mean of deposits



According the deviation in the expectation of the mean, it is observable that the static planning is rather sensitive for a bad estimation both positively and negatively, since the route is predetermined and then fixed and will not be changed during the simulation horizon. Most of the other policies have their minimum in total costs per collected liter at around 1, meaning that the more accurate the estimation is in relation to the true mean, the better the policies work. For the policies dynamic MayGo and dynamic All this fact is not applicable. It appears better to underestimate the mean. This is due to the bad coping with overcapacity that these planning options accompany. The lower the number of expected deposits, the fewer May-Go jobs are scheduled, since the number of Must-Go jobs increases. Thus, if the amount of jobs per day is not constraint by any threshold, the filling up on May-Go jobs in a schedule causes unnecessary travel expenses.

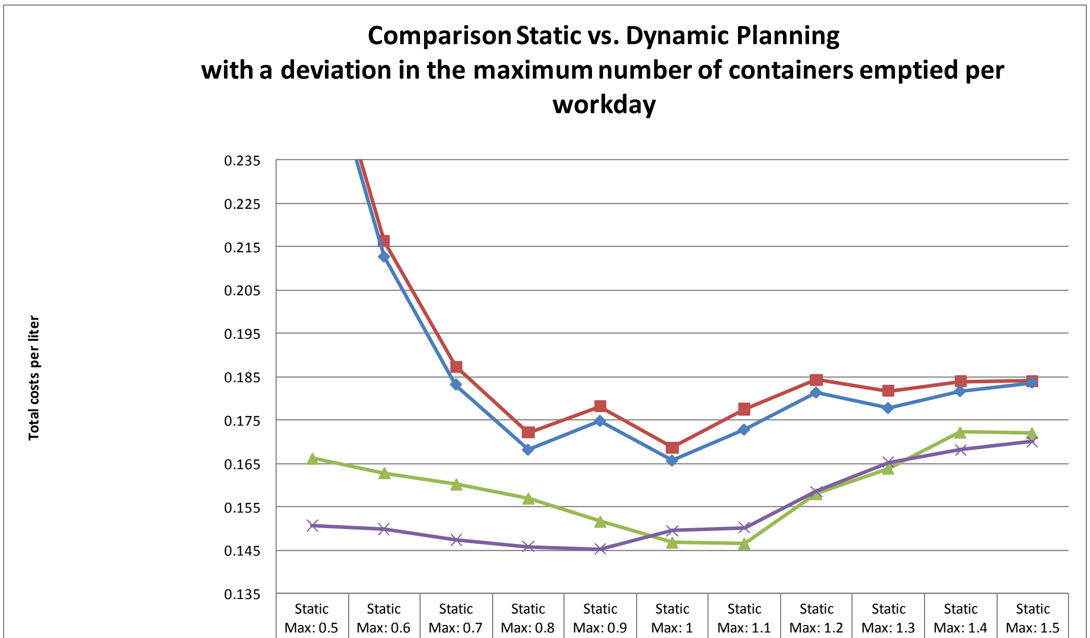
8.3 Review of rescheduling under 90,000 L target capacity and sensors

For graphs see appendix A29

As for the experiments conducted for the four rescheduling options under a target capacity of 90,000 liter and the possible use of sensor information, it appears to be that sensor-gained insights on the actual container volume helps a lot to improve the performance of the proposed policies. In the case of 378 containers these improvements are not that clear, however, seen the results of the 700 container case the decrease in costs due to the sensors are rather large for all of the tested rescheduling options. Again as already elaborated earlier the rescheduling options 2 and 3 seem to be the most beneficial for the system performance. This rather unexpected, since earlier it could be assumed that the rescheduling of all the trucks in case of a capacity problem might work out better when there is no capacity slack in the container selection. However, this does not appear to be the case and rescheduling option 2 (a truck only gets rescheduled in case of a problem) can be considered to perform the best in both the static and the dynamic (MayGoFixed) set-up. Also it became obvious that with sensor information rescheduling is almost never necessary, since it can be determined with high precision whether the container content of a following container still fits inside a truck or not – this is also mainly due to the fact that the deposits are not the fast throughout a day (in the simulation this has been modelled by a daily increase in the night hours).

8.4 Improvement opportunities of dynamic planning

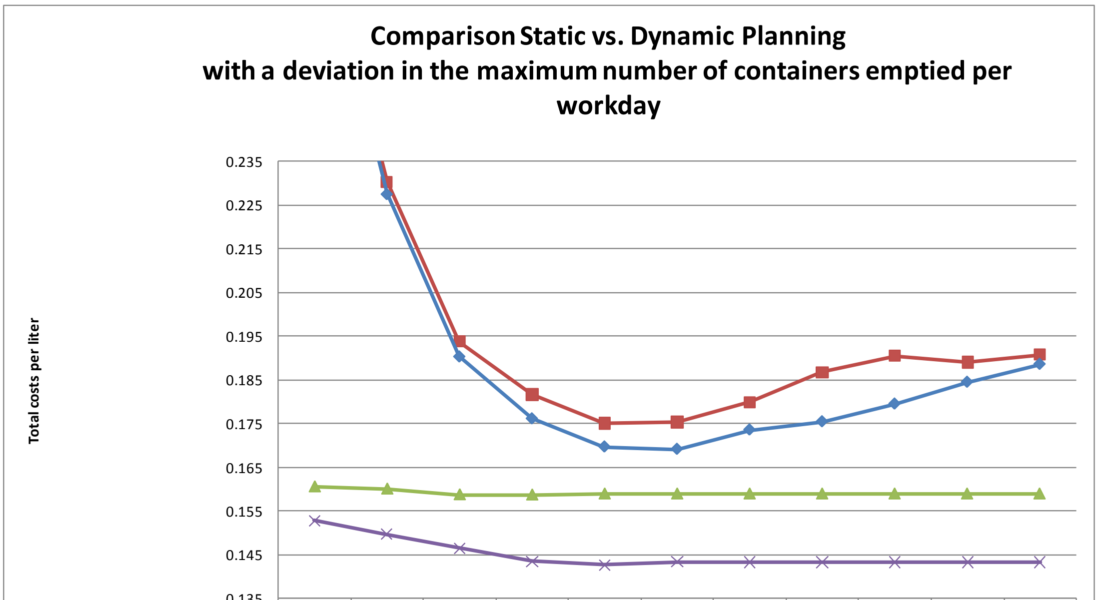
378 containers – Variation in the allowed workload per day



	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Static	0.274	0.216	0.187	0.172	0.178	0.169	0.177	0.184	0.182	0.184	0.184
Static Sensors	0.271	0.213	0.183	0.168	0.175	0.166	0.173	0.181	0.178	0.182	0.184
Dynamic (MayGoFixed)	0.166	0.163	0.160	0.157	0.152	0.147	0.146	0.158	0.164	0.172	0.172
Dynamic (MayGoFixed) Sensors	0.151	0.150	0.147	0.146	0.145	0.149	0.150	0.158	0.165	0.168	0.170

Variation of StaticMax (first row; 1=default/no effect)

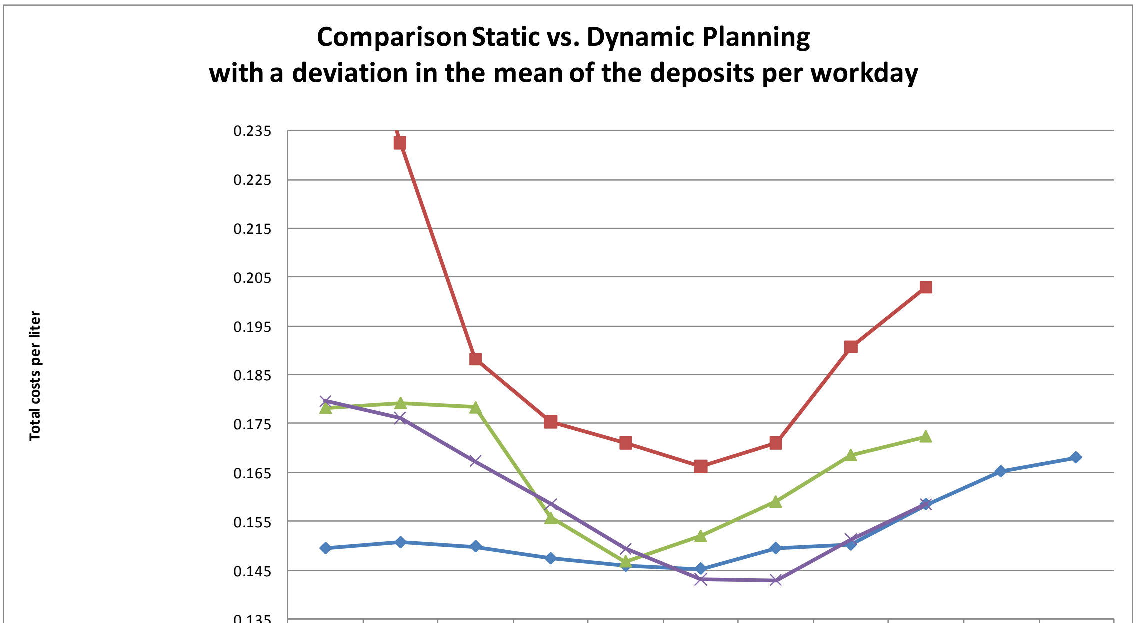
700 containers – Variation in the allowed workload per day



	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Static	0.296	0.230	0.194	0.182	0.175	0.175	0.180	0.187	0.190	0.189	0.191
Static Sensors	0.294	0.228	0.190	0.176	0.170	0.169	0.174	0.175	0.179	0.184	0.189
Dynamic (MayGoFixed)	0.161	0.160	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159
Dynamic (MayGoFixed) Sensors	0.153	0.150	0.146	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143

Variation of StaticMax (first row; 1=default/no effect)

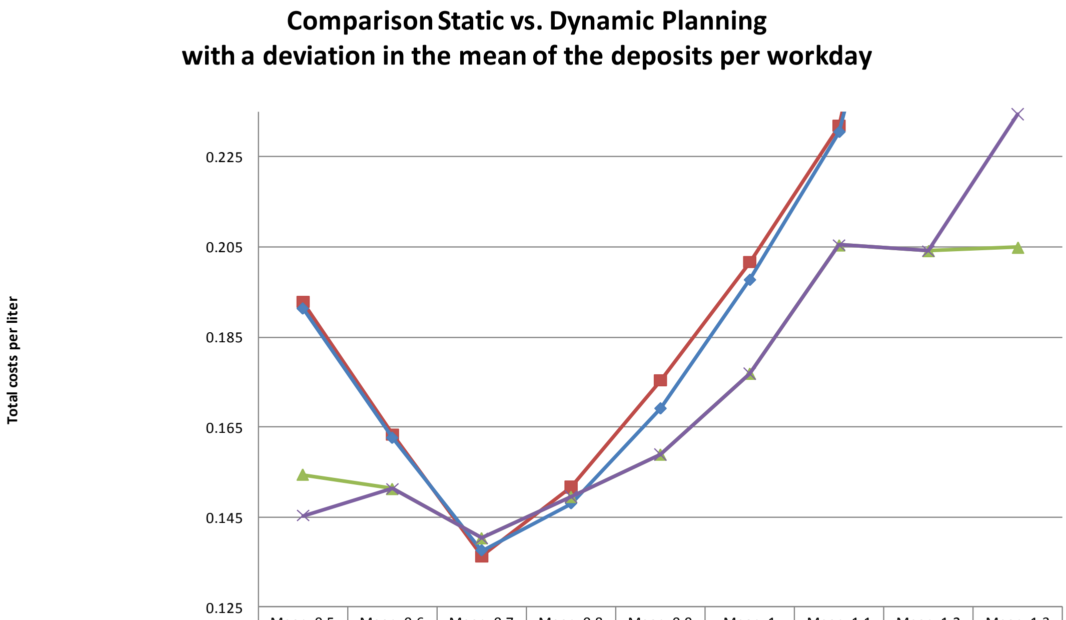
378 containers – Variation in the mean of the deposits per day



	Mean: 0.5	Mean: 0.6	Mean: 0.7	Mean: 0.8	Mean: 0.9	Mean: 1	Mean: 1.1	Mean: 1.2	Mean: 1.3	Mean: 1.4	Mean: 1.5
Static	0.281	0.232	0.188	0.175	0.171	0.166	0.171	0.191	0.203		
Static Sensors	0.149	0.151	0.150	0.147	0.146	0.145	0.149	0.150	0.158	0.165	0.168
Dynamic (MayGoFixed)	0.178	0.179	0.178	0.156	0.147	0.152	0.159	0.169	0.172		
Dynamic (MayGoFixed) Sensors	0.180	0.176	0.167	0.159	0.149	0.143	0.143	0.151	0.159		

Variation of Mean (first row; 1=default/no effect)

700 containers – Variation in the mean of the deposits per day



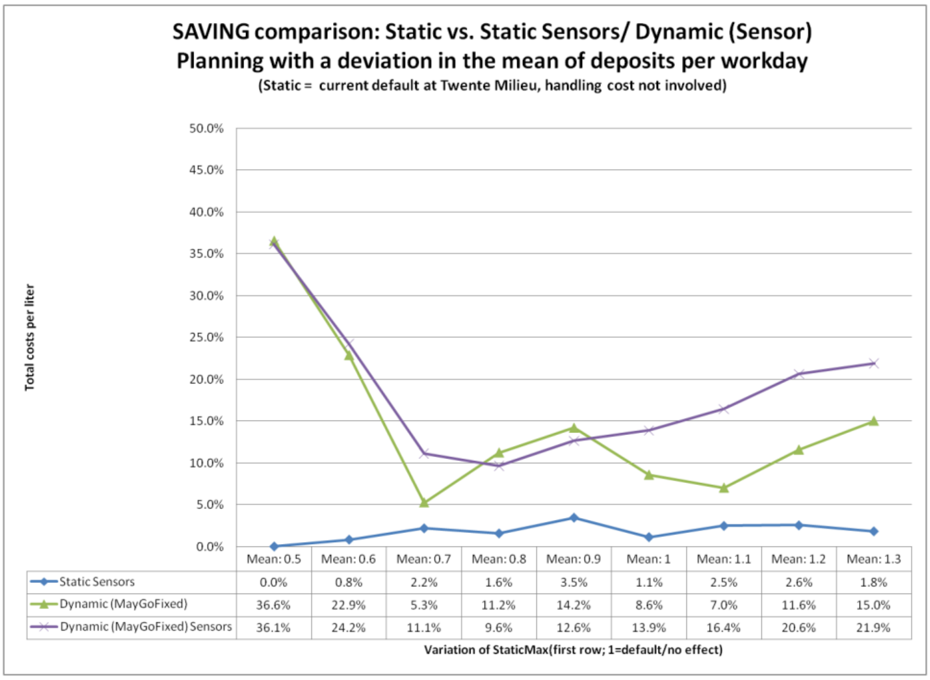
	Mean: 0.5	Mean: 0.6	Mean: 0.7	Mean: 0.8	Mean: 0.9	Mean: 1	Mean: 1.1	Mean: 1.2	Mean: 1.3
Static	0.193	0.163	0.136	0.152	0.175	0.202	0.232	0.320	0.356
Static Sensors	0.191	0.163	0.138	0.148	0.169	0.198	0.231	0.307	0.343
Dynamic (MayGoFixed)	0.154	0.151	0.140	0.149	0.159	0.177	0.205	0.204	0.205
Dynamic (MayGoFixed) Sensors	0.145	0.151	0.140	0.149	0.159	0.177	0.205	0.204	0.235

As can be seen in the in the figures on the two previous pages, it becomes evident that the dynamic planning options, either with or even without the additional application of level sensor can improve the system performance very noticeably. In general, the savings that can be obtained in the default through the application of sensors is about 2-3 cost units. In the 300 container scenario, the distance between the static option without sensors and the dynamic option (MayGoFixed) with sensors is around 2 cost units at the StaticMax of 1. For the 700 container case it even looks better, since a decrease in costs of 3 cost units can be realized. In both scenarios the dynamic planning method by far outperforms the static options.

If a look is taken towards the mean variation in the disposal amount, sensors normally account for a cost saving of 2 cost units. With a high variation of this type again the dynamic option performs rather well. However, there is something interesting to observe; the static option that includes level sensing in the containers appears to be very cost efficient with a mean variation below the default of 1. A reason for that could be that the static option is much more stable with regards to system nervousness and thus has an advantage over the dynamic option which reacts rather quickly to changes in demand. In the 700 container case, however, the differences between all of the tested policies seem to be very small. It could be possible that the two trucks that are used in this scenario are responsible for this equilibrium, since the offered capacity to empty all the containers is more than sufficient. Thus the dynamic policy cannot show its potential, because the situation is not restricted enough according the capacity used.

8.5 Saving potential of a dynamic waste collection process

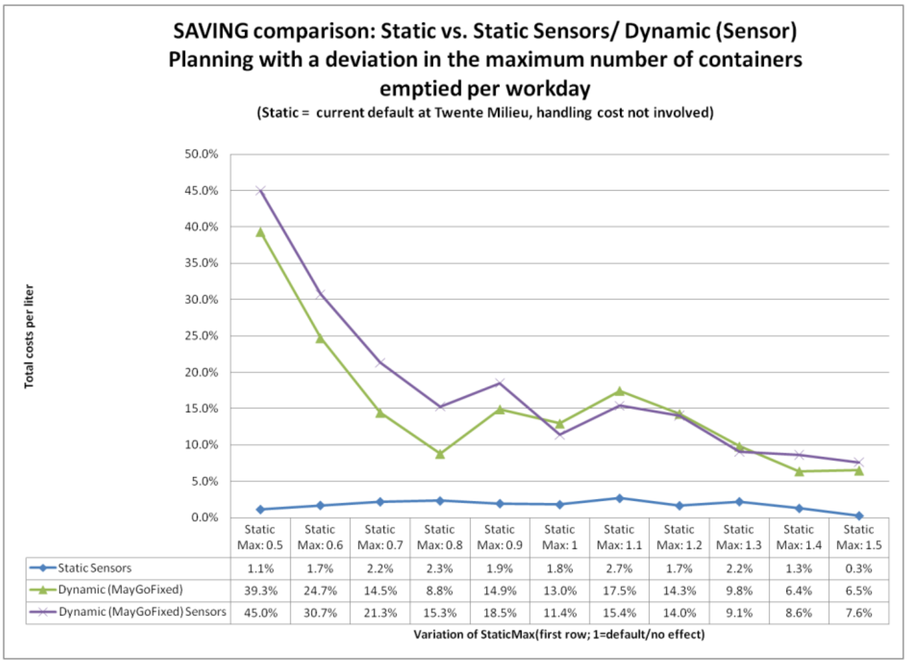
378 containers – Saving potential w.r.t. a variation in the mean of the deposits per day



	Mean: 0.5	Mean: 0.6	Mean: 0.7	Mean: 0.8	Mean: 0.9	Mean: 1	Mean: 1.1	Mean: 1.2	Mean: 1.3
Static Sensors	0.0%	0.8%	2.2%	1.6%	3.5%	1.1%	2.5%	2.6%	1.8%
Dynamic (MayGoFixed)	36.6%	22.9%	5.3%	11.2%	14.2%	8.6%	7.0%	11.6%	15.0%
Dynamic (MayGoFixed) Sensors	36.1%	24.2%	11.1%	9.6%	12.6%	13.9%	16.4%	20.6%	21.9%

The saving potential that could be achieved in the simulation of the 378 container scenario is higher the lower the mean is turning out to be throughout the simulation, since then the dynamic policy can react quickly in order to decrease unnecessary travelling of the truck fleet. The smallest saving that was realised by the dynamic policy that was additionally relying on sensor data was 10% improvement in costs in comparison to the regular static option without sensors. In general the dynamic policy with sensors performed the best – in the default scenario of almost 14% could be saved in travel, handling and penalty costs combined. The static option with sensors was not performing that incredibly better than the same option without the senor information, thus the improvements of that policy can be seen as irrelevant.

378 containers – Saving potential w.r.t. a variation in the allowed workload per day



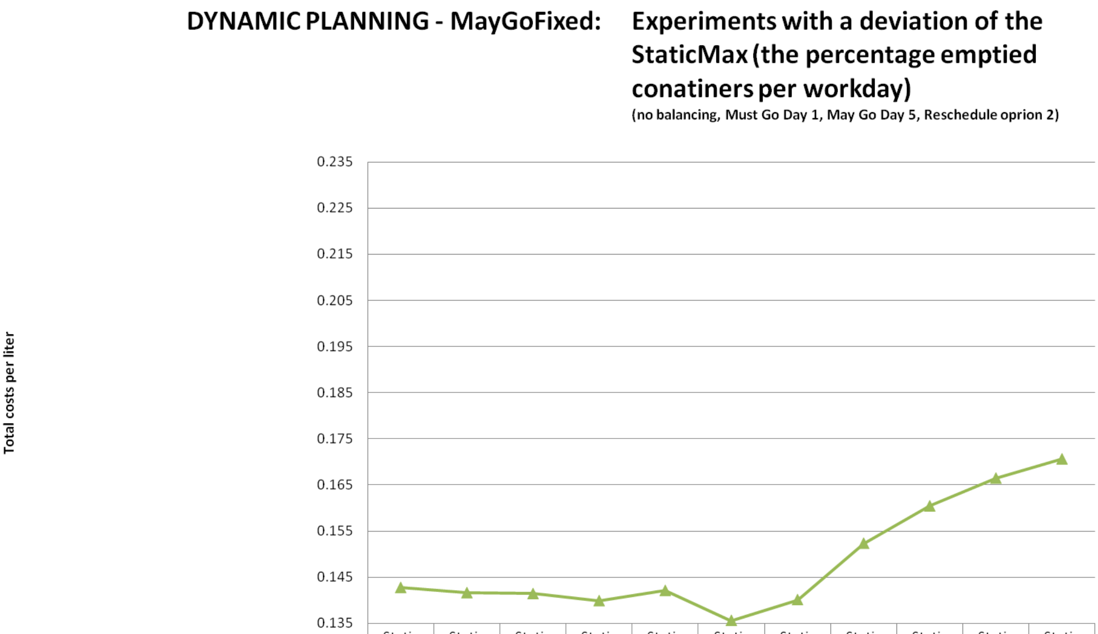
	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Static Sensors	1.1%	1.7%	2.2%	2.3%	1.9%	1.8%	2.7%	1.7%	2.2%	1.3%	0.3%
Dynamic (MayGoFixed)	39.3%	24.7%	14.5%	8.8%	14.9%	13.0%	17.5%	14.3%	9.8%	6.4%	6.5%
Dynamic (MayGoFixed) Sensors	45.0%	30.7%	21.3%	15.3%	18.5%	11.4%	15.4%	14.0%	9.1%	8.6%	7.6%

The simulation study has shown that the use of a dynamic collection approach has high potential of adding value to the Twente Milieu N.V. The highest savings can be accomplished when the number of allowed container collection per workday is reduced, since then the capacity slack for the planning decreases as well. The higher the StaticMax (number of jobs per day) the lower the potential savings for the dynamic option become. Besides the dynamic policy appears to cope better with an increase of the mean of deposits in comparison to the static option – especially when sensors information is involved.

As for the comparison of the dynamic and static option only seen the deviation of maximum workload per day against the total costs per liter, it can be observed that the static option never even comes close to the dynamic options. At a StaticMax of 22% of the total container population (StaticMax=1) is the closest the static option can approach the dynamic one. Thus in this respect the dynamic policy is significantly better than the static one – it is almost 3 cost units cheaper than the static policy. Very interesting in the 378 container scenario is the observation that a variation of the mean appears to be beneficial with the static sensor option as well as for the dynamic sensor option. Especially when the fluctuation in the mean decreases (values <1), the stability of the system increases and therefore the static option is the least nervous and reaches a good value for the total costs per liter - also with the help of the trustworthy forecast based on the sensor information.

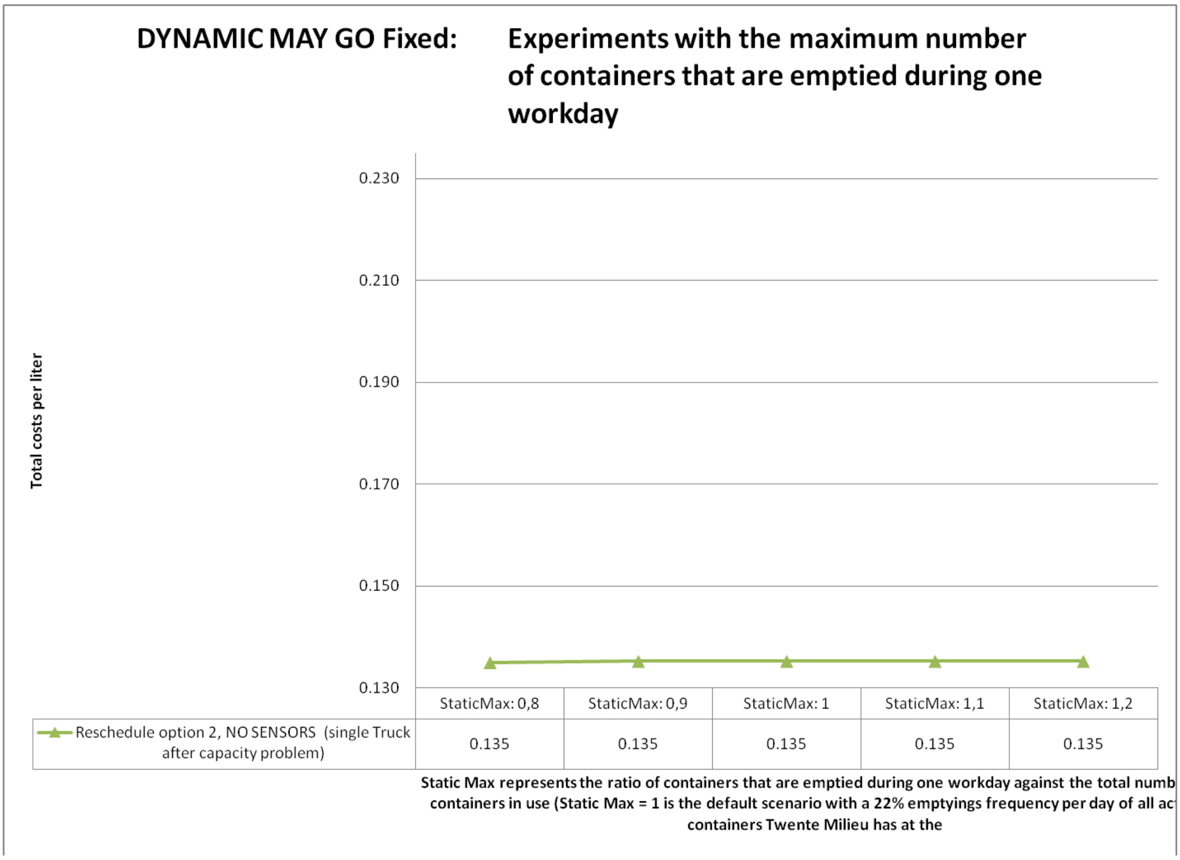
The most important fact that could be reviewed in the improvement results is that the more instable the system is the more valuable a dynamic planning policy becomes.

378 container case of the Dynamic MayGoFixed policy:



	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.143	0.142	0.141	0.140	0.142	0.136	0.140	0.152	0.160	0.166	0.171

378 container case of the Dynamic MayGoFixed policy:



The most astonishing saving potential becomes, however, visible when a look is taken on the policy cost development under a varying maximum allowed workload per day. Since, Dynamic MayGoFixed has almost similar noticeably lower costs than the static option when the StaticMax drops, it can be seen that even with a decrease of 50% (!) of container emptyings per day the target of the policy can be reached. Thus, even if Twente Milieu only empties 11% of the entire container population during one workday, then penalties would almost not change at all, using dynamic routing. **Therefore, the true saving potential of dynamic waste collection towards the current method according penalty and travel costs equals 45% or even more!**
The savings of the dynamic policy at a StaticMax of 0.5 (50% less containers emptied per day) in comparison to the static policy mainly derive from the penalty costs that could be decreased immensely; see the table below:

	TravelCosts	HandlingCosts	PenaltyCosts
Static Policy	2114330.8	1562040	5632096.797
Dynamic policy	2212837.6	2047092	753553.5284
Difference between policies	-98506.8	-485052	4878543.268
Dynamic policy in comparison with static policy	104.7%	131.1%	13.4%

8.6 Summary computational results

In this section, the results that have been presented in detail beforehand are again summarized in a compressed form in order to enable the reader to re-focus on the main issues that have been found out regarding the simulation study.

- Static planning:
  - Rescheduling does not have incredibly much effect; the option to just reschedule the truck that actually has trouble with it capacity should be re-planned in order to schedule as efficient as possible, more rescheduling causes much higher costs.
  - Sensors have effect, since the additional information is used to make an enhanced schedule.
  - The penalty ratio of 0.7 seem adequate, since with a StaticMax of 22% as maximum workload a fill rate is reached of 63% which comes close to reality.
  - Useful in stable situations, sensors, however, the impact is limited when the demand is underlying heavy fluctuation.
  - Policy works slightly better if more volume is deposited than expected.

- Dynamic Planning (without workload balancing or May Go jobs) / Normal:
  - The Must-Go day should not be taken too high or too low. Especially in stable situations the Must-Go day can be smaller, since system disturbances are not that common. In unstable situations a higher Must-Go day performs better, since already it is travelled to collect more containers which decrease the penalties of late emptying. Overall, a Must-Go day between 1.5 and 2.5 (thus on average 2.0) appeared to work out the best in most situations.
  - A Must-Go day of 0 yields very bad results, since only the jobs are considered that are due on the particular day – thus the risk that many containers within one day is rather high. Also this is an indicator that two trucks do not have enough capacity to cope that many containers in one day alone.
  - Much rescheduling again only has very limited impact on positive results with regards to the total costs per collected liter. Reschedule option 2 (only the truck that has a problem) can be considered the most favourable option.
  - Sensors have modest positive effect on the cost reduction, however only in the case of a strong sinus variation. Seen the other type of variation, the impact of sensors is rather limited.
  - In this policy it appears better to slightly overestimate the volume that is deposited; with a lower expectation the penalty costs explode. This is due to the fact that with a low expectation the emergency planning probably has to be executed quite a lot during the simulation, meaning that the capacity of the truck is that kind of situation just too insufficient. Therefore, too many containers are emptied too late.
  - The number of emptyings is less than with the static method, but more unbalanced.
  - This policy performs quite well, especially with sensor information.

- Dynamic Planning (with workload balancing, without May Go jobs) / Balance:
  - The Must-Go day should not be taken too high or too low. Especially in stable situations the Must-Go day can be smaller, since system disturbances are not that common. In unstable situations a higher Must-Go day performs better, since already it is travelled to collect more containers which decrease the penalties of late emptying. Here a Must-Go day between 1.5 and 2.5 appears to work the best in most of the situations under uncertainty.
  - Balancing alone does not work that well, but by using sensor data it can be enhanced.
  - The mean and Expec variation causes a similar system behaviour as in the dynamic normal policy.
  - The number of emptying is higher than in the dynamic normal option, but they are more balanced.
  - For 378 containers and two trucks balancing however has only a limited effect, since the capacity is more than enough to cope with the demand, even in an unbalanced mode. However, also in the 700 container scenario the dynamic balancing method does not show the best results in the overall situation.

- Dynamic Planning (without workload balancing, with May Go jobs) / MayGo:
  - Here the relation between the Must-Go day and the May-Go day was studied: The optimal was found at Must-Go day 1, May-Go day 3 for 378 containers and Must-Go day 1, May-Go day 5 for 700 containers. With high uncertainty high values for both Must-Go day and May-Go day appeared more favourable while it was the opposite for stable systems with low uncertainty.
  - The sensor information for a Must-Go day 1 and May-Go day 1 has a huge effect, especially in cases of high uncertainty.
  - The sensor information for a Must-Go day 1 and May-Go day 5 has a fewer effect, since it is already travelled more than needed, however in uncertain situation still the benefits of sensor information are visible.
  - Rescheduling more often is not that favourable, as could already be seen for the previous policies.
  - Overestimation of the deposited volume works better in this policy, meaning that the goal of the policy is not reached and that it aims to empty too much containers on a May-Go level. Only constraining the proliferating addition of May-Go jobs might solve this issue.

- Dynamic Planning (without workload balancing, with fixed number of Must- and May-Go jobs) / MayGoFixed:
  - This is the policy that performs overall the best under the several types of uncertainties that have been tested. Only a high sinus variation cannot handled extremely well, however also here the results of this policy are only varying 0.2 cost units from the best performing policy under a sinus variation. Thus the winner under the various dynamic policies can still be seen as Dynamic MayGoFixed, even given this small weakness it has.
  - A high May-Go day is performing well here (5), since it increases the freedom of choice for the May-Go jobs, from which the best are included in the schedules. The maximum amount of jobs is constraint by the maximum workload.
  - More frequent rescheduling again does not have that much impact.

- Dynamic Planning (with workload balancing, with May Go jobs) / All:
  - The positive effect of the addition of May-Go jobs and the balancing approach cancel each other out; in fact overbalancing is the result.
  - Costs are continuously high for all settings and do not differ a lot from each other. In general it seems to be a quite bad policy that does not reach its goal well to decrease the costs per liter emptied.
  - The policy even works worse than the static option in most situations.

- Dynamic Planning (with workload balancing, with fixed number of Must- and May-Go jobs) / AllFixed:
  - This policy behaves similar to the dynamic MayGoFixed policy; an additional positive impact of the balancing algorithm is not visible. Again it becomes obvious that balancing and the addition of MayGo jobs work against each other; thus do not perform better as a combination.

- Improvements:
  The dynamic MayGoFixed policy has large improvement potential upon the static planning that is pursued at the Twente Milieu N.V. at the moment; in particular the more a system appears to have high uncertainty of one of the three kinds of variation used in the simulation (sinus, uniform, standard deviation) in the deposits the more beneficial the dynamic approach becomes.

- Level sensing:
  In general all the policies worked better under the use of sensor information than without it.

- Saving potential of dynamic waste collection:
  The savings that can be obtained by implementing a dynamic waste collection methodology regarding the total costs per collected liter refusal can reach up to **+45%** in comparison with the currently used methodology.

9 CONCLUSIONS

In this chapter, all the relevant conclusions and findings revealed in the previous chapters are summarized and further explained according their importance for the Twente Milieu N.V. Mainly, the conclusions provided here are based on the computational and non-computational experiments. The gathered insights gained in this chapter will be the input of chapter 9, providing a set of recommendations to Twente Milieu in order to increase their performance on the field on dynamic waste collection.

There are several conclusions that emerged throughout this research that ought to be mentioned in this chapter. First of all, the volume determination of refusal within a container cannot be solely done with the amount of clap openings – and also not with the relation between the clap openings and the weight of the individual containers. It would be possible to do so, however with no tools that are accessible for the Twente Milieu N.V. The density of the waste can be determined within each of the containers. The average alone of 0.11kg per liter waste is not accurate enough to make a correct estimation on the true volume inside a container – as can be reviewed in the chapter on data analysis. Moreover, the true capacity of the 5m³ containers is not 4800 liter as currently assumed, but only 3900 liter, since 22-23% of the original container content is lost due to a pyramid-like fill pattern within an underground container. This has been studied with the help of a paper-based container model with a scale of 1:10.3. The confidence level used was 90%. With a confidence of 95% at least 21% of the volume is lost, thus the useable container volume equals 4m³ in this case. Consequently, a volume determination formula has been developed (appendix A28) that only needs one non-fixed parameter to estimate the volume in a container – namely the altitude of the top of the growing refusal pyramid. To accurately determine this parameter a more accurate measurement system has to be introduced. The research showed that ultrasonic sensors are quite fitted for the needs of the Twente Milieu N.V. because of their low costs and their useful features. One of these features is that the emitted sound waves are absorbed by highly absorbing material, like mattresses. However, in realty it will actually never occur that an underground container get filled only with highly absorbing materials. Also the container supplier of the Twente Milieu N.V, B-waste already started a test with ultrasonic sensors that showed quite positive results. Now the sensors ought to be tested in real containers of Twente Milieu – a selection of test containers can be found in appendix A19.

Next to the volume determination issue, other problems have been found with respect to the underground containers used. There are several containers that suffer heavily for water leakage, violation, low battery power and material deterioration. These problems cause several unpleasant effects and should be tackled as soon as possible. Especially, the current supplier of the containers, B-Waste, should be included in the resolving of these issues.

Moreover, the multi-containers locations appear to have various troubles as well. Firstly, the capacity for deposit space seems to be overestimated conform the data analysis. Secondly, the waste deposited in the individual containers of a multi-container location is unevenly spread. This is causing the collector to empty a location (Dutch: "zuil") more than once given the period of time where it would take until all of the containers have been physically full once. Because of this fact, the collection cannot be done very efficiently – not now and also with a dynamic routing approach the true potential of that policy will not be truly realized if the problem of the uneven spread of refusal is not solved. Fortunately, there are possibilities to solve this issue by installing electrical guidance system for users. Such a system attends the user which container to use, so that waste will be spread more evenly among containers in a group.

With regards to the communication at Twente Milieu there is to say that data assessment is rather difficult at the moment, since information is wide-spread throughout the company and not easily accessible. Central information points with clear data housekeeping are not fully established yet. Also the use of two different databases (Mic-o-Data and B-waste) for the container control is rather unfavourable.

To increase the capacity in the collection process the opening times of the Twence installation might be used as bottleneck of the operation of Twente Milieu. Thus with the introduction of shifts and Saturday work, a lot of extra labour potential will be available, resulting in a lower number of trucks that are needed for the collection of the container population. With the measures mentioned above, even two trucks would be enough to serve 1500 containers including a variation in workload per day of 20%. This is a very helpful insight if additional investment capital is needed for bigger projects or if the municipalities are heavily forcing the Twente Milieu N.V. to save funds.

Causes of data pollution vary in the underground container project, however manual resetting and the transfer faults of the Welvaarts system are figured to be the main causes. This kind of data pollution can be dealt with RFID applications that recognize the containers ID's automatically and register a reset and the container weight in the system (via Welvaarts and ARIS). Active sensors would be attached to the trucks and passive tags with a three meter radius are attached to the container maintenance doors. Applying these technical, rather simple, but very useful tools might save Twente Milieu labour capacity, along with better housekeeping according to the data management will be possible.

Regarding the simulation study there is to say, that either balancing or the addition of MayGo jobs work in order to decrease the total costs per liter involved. The combination of the two, however, works counterproductive – the phenomenon of overbalancing is to observe, which causes the initially positive effects of each approach to be cancelled out by the opposed approach. In general, it was noticeable, that the addition of MayGo jobs – if their total amount is constraint from the top – performs quite well to increase the efficiency of the collection process.

The MustGo day should not be picked too high nor too low, since the goal is to find the trade-off between the additional travelling of the fleet – which costs money – and the risk of emptying containers too late, which in turn would be responsible for penalty costs. In the tested scenario a MustGo day between 1.5 and 2.5 can be considered the best. On average this equals a MustGo day of 2, however, Twente Milieu might need to slightly adjust this number so that the full potential of the dynamic routing methodology can be exploited.

As already mentioned, the addition of MayGo jobs works very well, if these are limited; in the tested model, a MayGo day of 5 seemed to be the best, because it left the algorithm enough freedom to pick the most practical containers that could be included into an existing route.

Unexpectedly, more frequent rescheduling was not that beneficial in any of the dynamic or the static policies. Thus, it can be said that rescheduling only the truck that has trouble with the capacity limitation ought to be due to re-planning – all the others should just continue their schedules and routes.

Further, it became very clear that the policy dynamic MayGoFixed, which works under a constraint maximum workload, outperforms all the other dynamic policies in almost all the variations that they have been tested on. Only a very high sinus variance was not that easily to handle by the dynamic MayGoFixed policy. Nonetheless, the results were not that far away from the best performing policy in that respect, thus the performance was still very acceptable.

When benchmarking the above mentioned policy against the static planning option that represents the current way the collection of the underground containers is handled by the Twente Milieu N.V., it was very well visible that there are rather large cost saving possibilities connected to the implementation of a dynamic planning option upon the static on. Especially, in scenarios where the system had to undergo a vast amount of variation the improvements in comparison to the current method were tremendous. This is also equivalent to the conclusion Johansson made in his study of the Malmø recycling facility. Thus, the more variation is incorporated in a system the more it can benefit from a dynamic planning approach – and Twente Milieu has a vast amount of variance in its operational environment, so the positive effects due to a dynamic approach in the collection process will be very noticeable. Even for the default scenario of the simulation study at a maximum workload of 22% of all the containers, the dynamic policy with sensors could decrease the total costs per collected liter refusal from 17.5 cost units to 14.3 cost units (700 container scenario) – thus the costs could be reduced by 1-(17.5/14.3)=18.3%. Again it is to stress that that is the minimum amount of savings that could be realised – with a lower workload the saving potential is a multiple of the previously mentioned one. For instance, if the maximum workload allowed per day is decreased by 50%, the advantage of a dynamic routing becomes extremely visible, most likely resulting in a reduction in cost of 45% or higher.

At last, there is to mention that all the policies were producing better results given sensor information; therefore it can be assumed that having an accurate insight of the actual fill level of each and every container is much better than to approximate the fill rate based on clap openings.

Finally, if Twente Milieu really has to struggle with capacity problems in the coming future, dynamic waste collection is perfectly suited to handle the same amount of work or even more with much less capital expenditure.

10 Recommendations & remarks

Chapter 9 will discuss important recommendations and remarks that should be taken into account by the Twente Milieu N.V. based on the conclusions found throughout the internship project. The recommendations are subdivided into short-term and long-term recommendations, since some aspects need more attention before an upcoming implementation of a dynamic routing process than others. Thus, the short-term recommendations mainly consider advises to should be cared about deeply before the actual collection methodology is altered in reality. The long-term recommendations on the other hand are more directed towards a future success of the company's well-being in general and of course the underground container project.

Short-term recommendations (before the implementation):

- It should be looked for a level sensing system that can provide enough accuracy for the volume determination within the containers – ultrasonic sensors appeared to be a nice option in that respect, since they are relatively cheap and fulfil all the requirements needed to measure the altitude of refusal in a container. Moreover, B-waste already started it research on this field with the same type of sensor.
- A test ought to be conducted with the sensors in some of the containers of Twente Milieu (see appendix A19)
- The true capacity of a 5m³ container has been estimated to be 3900 liter based on a 90% confidence interval retrieved from a container size simulation study. This is an indicator that the lost volume of 10% of the original volume was considered wrong so far, however, it is just an indicator and no absolute result. To confirm this finding an experiment should be conducted with a real container and real trash bags, since the compression behaviour of the waste might be different from the simulated waste bags.
- The volume determination formula that can be found in the appendix A28 can be used in order to calculate the refusal volume within a container. In order to verify the correctness of the formula and the assumptions made, a confirmation experiment should be executed.
- More research should be done upon the variation the Twente Milieu is exposed in its operational environment. This is of outmost importance, since the type of variation decides which dynamic policy fits the best to the company
- RFID applications to avoid manual resetting and automated container identification can be seen as a valuable tool against data pollution and as slightly labour capacity increasing means.
- The 22-23% lost volume for a 5m³ container should be confirmed by a test with a real container and real waste bags to be sure that this newly emerged assumption is really reflecting the truth.

Long-term recommendations (mainly during the implementation and after):

- The data retrieval and assessment at Twente Milieu should be made easier and therefore central information points should be upgraded.
- Furthermore, the currently used two data bases of Mic-o-Data and B-waste should be integrated into one single platform, so simplify analysis of data.
- The issues connected to the water leakage, battery and other hardware issue should be solved on a mid-term bases
- In the long run, the Twente Milieu can think about the possibility to introduce shifts of Saturday work as means to enlarge the available labour capacity, especially if the cost pressure increases upon the company these might be useful tools to realize high cost savings.
- When the dynamic planning approach is implemented it should be related or similar to the previously described dynamic MayGoFixed policy, since that was the policy that worked the best for most variations
- When it ought to be decided to equip containers with level sensors, the fill velocity should be researched in order to make more accurate forecasts how long it takes for a container to overflow. With regards to this, it should not be looked at averages, but on the individual containers themselves.
- The Twente Milieu should try to collect as much data of the underground containers as possible and on a continuous basis. Only if there is quality and quantity of information input analysis can be performed – thus it ought to be strived to use all the means of data collection that mostly are already present at the company to open up more improvement potential. This advice mainly concerns data about the weight of the con-

tainers at emptying, the number of clap openings on a daily basis and before collection and also the altitude of the waste pyramid inside the underground containers at several points in time (preferably per hour for instance).

11 Scientific and societal contribution of this thesis

This research is a follow up on Stellingwerff's work regarding an efficient dynamic waste collection methodology. Already she tried to fill the gap in the literature for solid waste management and the inventory routing problem. In her and as well in this study the dynamic waste collection is mainly focussed on the container selection rather than on the routing of an efficient route itself. A general reason for this is that the distances in the real-life network between containers are not that far and thus also not that costly. This research intends to further give additional ideas and solution approaches about implementation issues that should be taken into consideration before a similar project that has been described here and in Stellingswerff's research will be executed in reality. In the main it can be considered to be a guideline in order to avoid unnecessary foreseeable pit-falls during an actual implementation.

In addition, this study has the societal contribution that – if conclusions will be used and recommendations will be put into practice – the municipal and individual costs of waste collection and the CO_2-footprint of the region involved can be reduced significantly. Thus, at the end resources could be used in a less wasteful manner.

12 Suggestions for further research

Although it was tried to conduct this research as thoroughly as possible due to time and other constraints perhaps not all the relevant issues could be treated. In general it has be shown during the execution of this research project that capacity determination inaccuracies and currently used assumptions were one of the most important causes for deficient results. As for this assessment it seems very handy to research more on the assumption used at the moment that did not get revised or verified in quantitative matters recently. Building up on that, I would strongly suggest examining the filling behaviour of solid waste in the applied underground containers more in depth. Especially the gradual compression of refusal might be of importance according to the actual volume of waste collection. In addition to this it should be more explored in the area of actual demand from a customer point of view. Earlier it has been shown that the customer behaviour is more based on guesses than on reliable data. To get better insights in that kind of behavioural circumstances a learning methodology could be designed for Twente Milieu that keeps track of changing customer expectations and conclusions derived from the data provided by underground containers.

Another problem that deserves more focus is the communicational and knowledge structure within Twente Milieu. Even though the communication in general leads to appropriate results at the end, a lot of effort is needed beforehand to collect all the necessary information that is valid to solve a certain problem. Mainly this is due to a wide spread and separation of knowledge within the company that makes it difficult to receive verified and complete data fast. Improving that shortage could be done by setting up a companywide knowledge sharing system that in its dimensions could be assessed more deeply. In that kind of system also the participation of the primary work force – the collectors – should be taken into account, since they are the people that face the implementation problems on a daily basis and also probably have some inspiration on how to solve them in a convenient way.

13 Evaluation & Reflection

My internship at the Twente Milieu was a very useful and enriching experience for me, and I am very glad about the fact that I was given the chance to conduct a follow-up research based on an earlier master project. The role of waste collection and processing is in my opinion very essential for the society we are living in and of outmost importance for environmental and health protection, as well as for the perceived quality of life in general.

I have the feeling that I learned a lot through this internship, especially in a very practical matter. As can be read in the introduction chapter, I carried out a wide variety of tasks and was able to gather quite some experience with, in particular, the extensive use of Excel in corporate reality. Also, for instance, organizing a brainstorm session with the managers that are concerned with the underground containers was very exciting. In general, I can say that I really liked to work at Twente Milieu and the colleagues I had there and I hope they share the same experience like me.

However, I also made some mistakes during the course of this project which I have to learn from for future projects. First of all, I should always write down every assumption I made, the major steps of a day, small and big discoveries and even simple notes on minor issues as an electronic (!) notepad version, including the date of data creation in the file name. I wrote down a lot, but however mostly on paper, which made it rather difficult in the end to fit together all the puzzle pieces that were needed for the report of this research. Thus, ordering very carefully and writing down simply everything electronically in such projects in order to remain the overview is the most impactful lesson I learned.

Moreover, I had to realize the hard way that I took the scope of the project way to wide and therefore included too many different subjects that I wanted to fit within the scale of my bachelor assignment. Later on I will focus more on fewer issues, but then a lot more in depth. It appeared to be better to have smaller, but several projects than one huge project where the organisation can get messy (which many times occurs, I could imagine).

Except for the above mentioned facts, which were the cause for a delayed submission of the report, I think I did a quite good job for the Twente Milieu N.V. and hope that they will use this report for many reviews during the implementation phase of the dynamic planning approach and that it will help to contribute to a even cleaner and resource saving Twente region.

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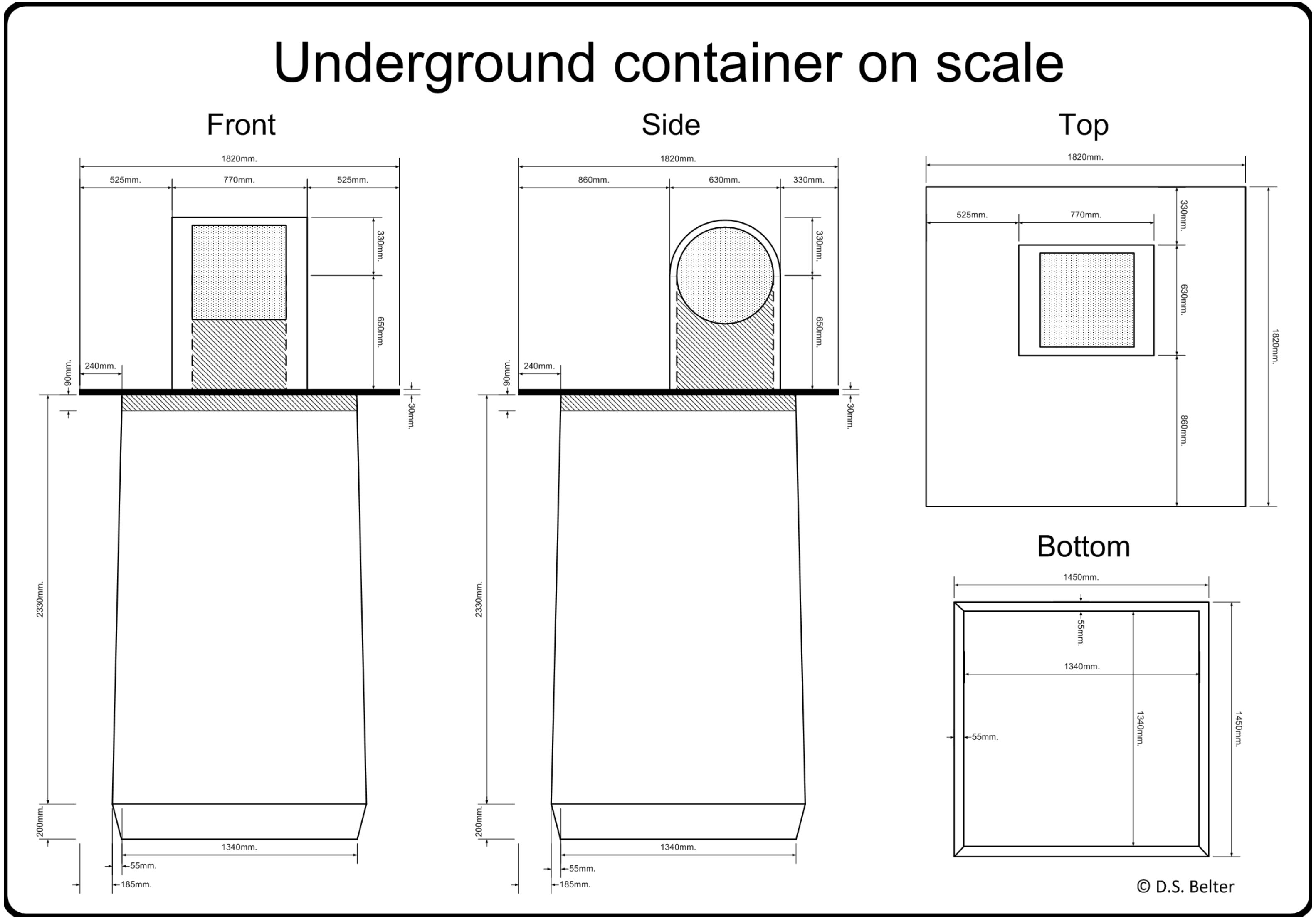
APPENDIX

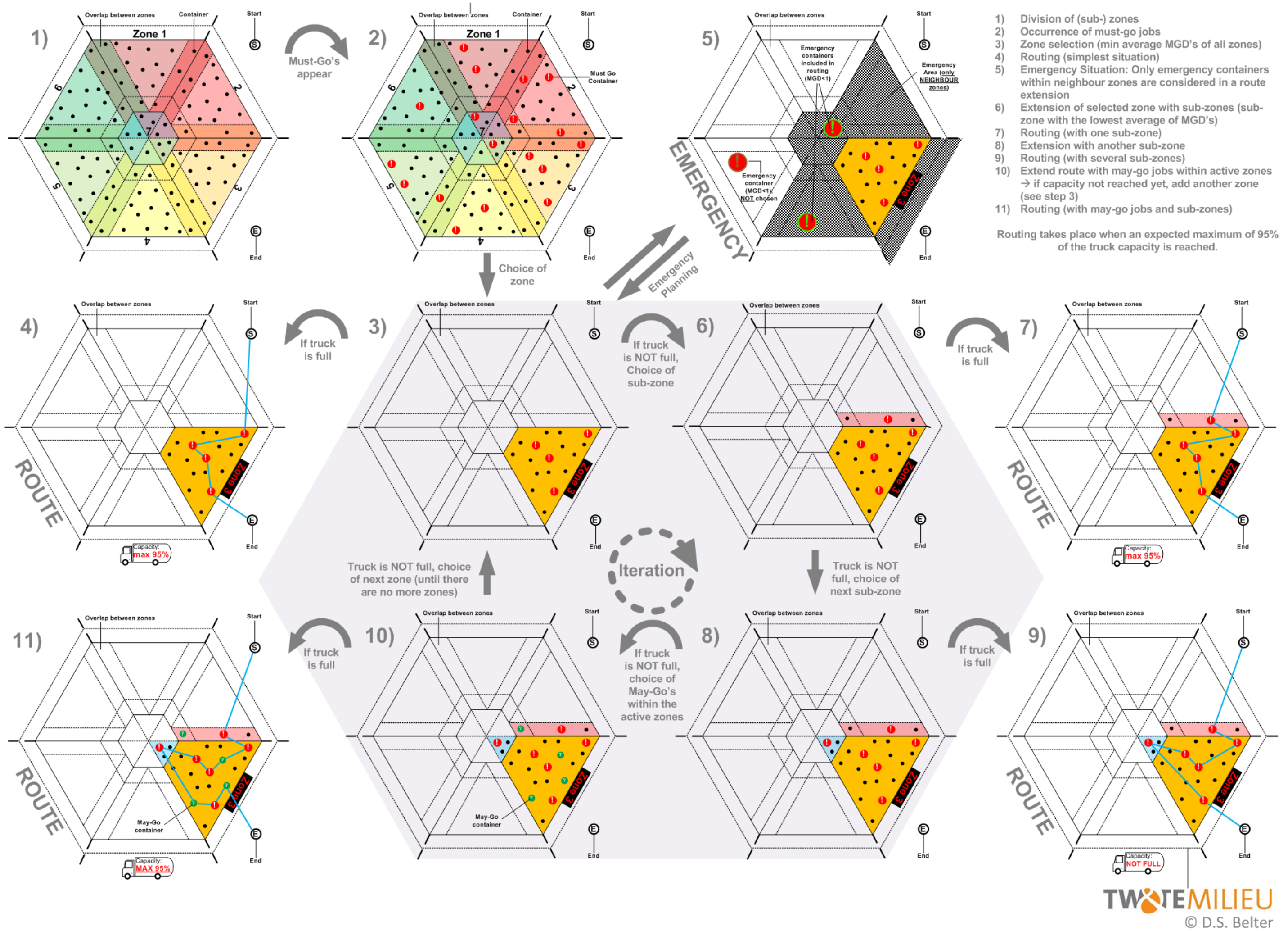
TABLE OF APPENDICES

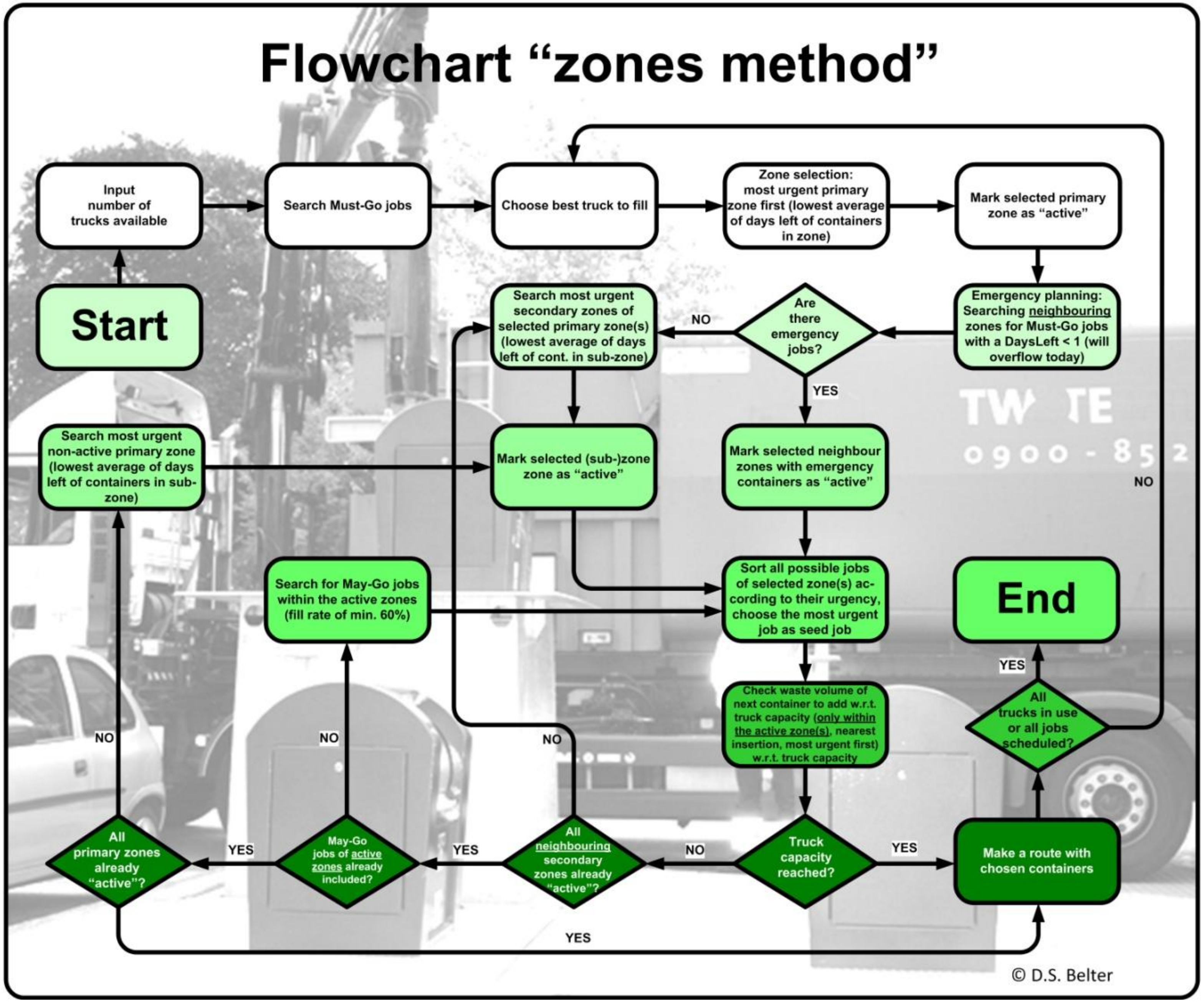
APPENDIX 1 – CONTAINERS ON SCALE

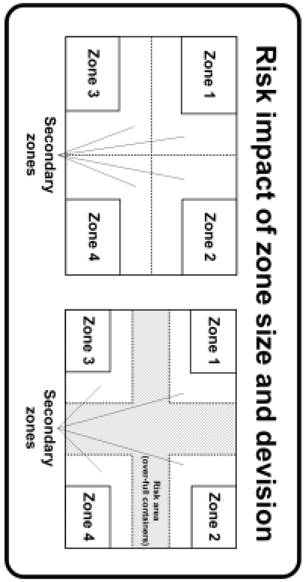


APPENDIX 2 – "ZONES METHOD" DEPICTION

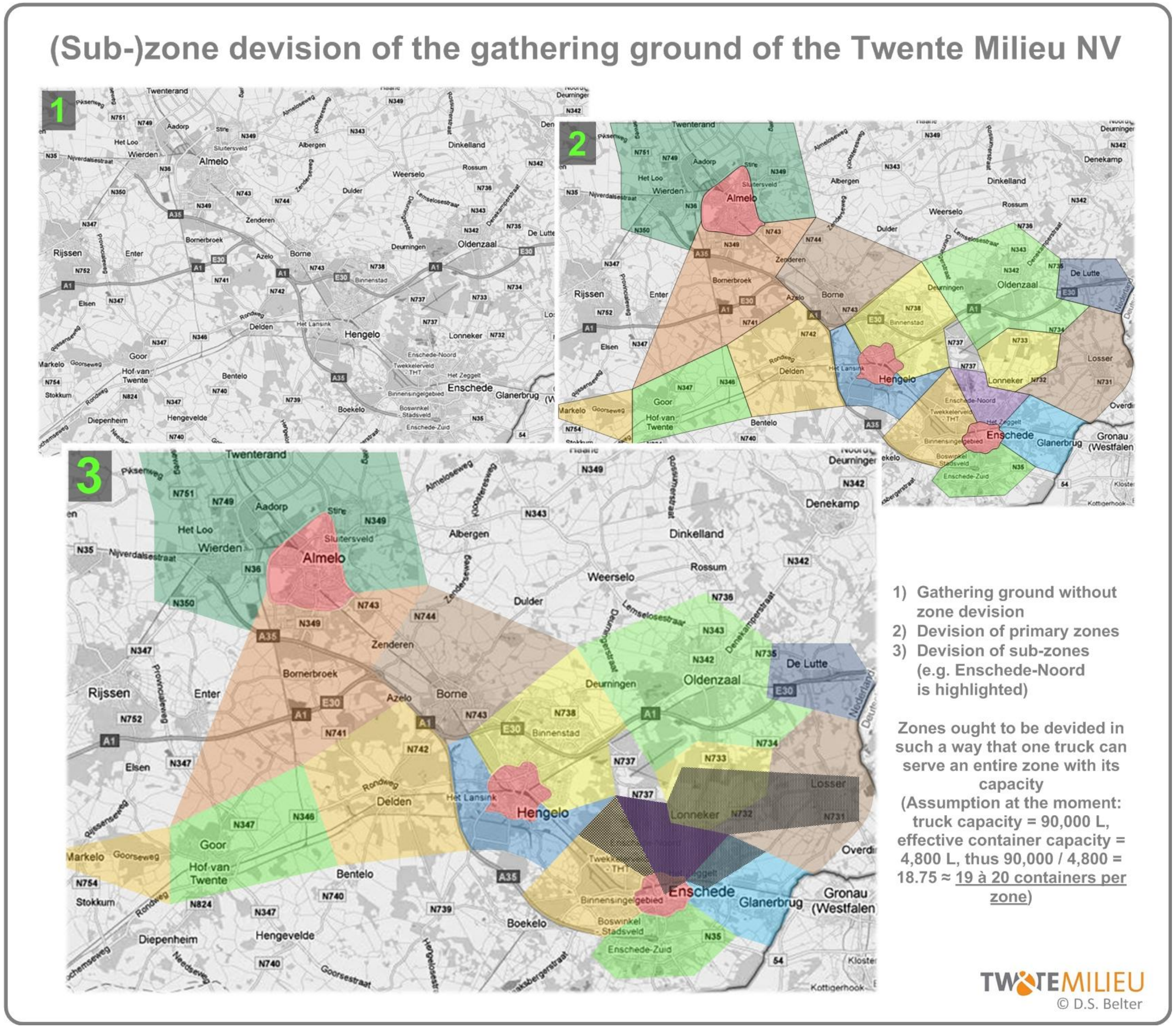
Concept: container selection & routing (zone first, route second, modified)




Flowchart “zones method”
Start
Input number of trucks available
Search Must-Go jobs
Choose best truck to fill
Zone selection: most urgent primary zone first (lowest average of days left of containers in zone)
Mark selected primary zone as “active”
Emergency planning: Searching neighbouring zones for Must-Go jobs with a DaysLeft < 1 (will overflow today)
Are there emergency jobs?
NO
YES
Search most urgent secondary zones of selected primary zone(s) (lowest average of days left of cont. in sub-zone)
Mark selected neighbour zones with emergency containers as “active”
Mark selected (sub-)zone as “active”
Search most urgent non-active primary zone (lowest average of days left of containers in sub-zone)
Sort all possible jobs of selected zone(s) according to their urgency, choose the most urgent job as seed job
Search for May-Go jobs within the active zones (fill rate of min. 60%)
Check waste volume of next container to add w.r.t. truck capacity (only within the active zone(s), nearest insertion, most urgent first) w.r.t. truck capacity
Truck capacity reached?
YES
NO
Make a route with chosen containers
All trucks in use or all jobs scheduled?
YES
NO
End
All neighbouring secondary zones already “active”?
YES
NO
May-Go jobs of active zones already included?
YES
NO
All primary zones already “active”?
NO
YES
© D.S. Belter


Risk impact of zone size and devision
Zone 1
Zone 2
Zone 3
Zone 4
Secondary zones
Zone 1
Zone 2
Zone 3
Zone 4
Secondary zones

Appendix 3 – "Zones method" Zone division



Appendix 4 – Presentation: brainstorm session

Content:

Brainstorm session

on the general and specific problems

connected to the underground container project

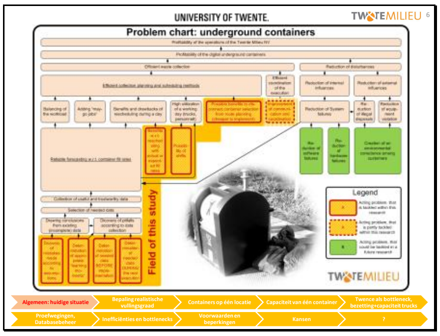

Brainstorm sessie:
Digitale ondergrondse containers
TWENTEMILIEU

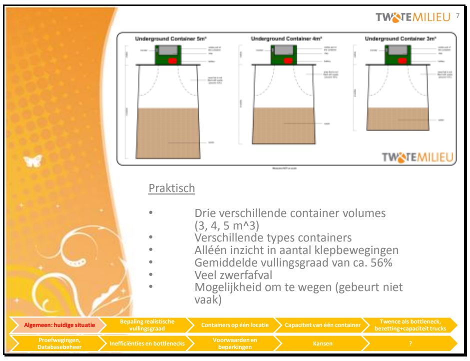

TWENTEMILIEU
Het in kaart brengen van de huidige situatie (algemeen)


Agenda 1/2
Het in kaart brengen van de huidige situatie (algemeen)
Realistische bepaling van de vullings-graad van de ondergrondse containers
De hoeveelheid ondergrondse containers op één locatie (quota en observaties)
Totale capaciteit van één onder-grondse container (i.v.m. het soorte-lijk gewicht van het gestorte afval)
Bezettingsgraad en capaciteit van zelfwegende vrachtwagens, Twence als bottleneck van de operaties van Twente Milieu


TWENTEMILIEU


Agenda 2/2
Proefwegingen en Databasebeheer (wat is waar te vinden, de noodzaak van drie verschillende databases, Welvaarts)
Zoektocht naar inefficiënties en bottlenecks
Voorwaarden en beperkingen van de huidige operaties, verstoringsfactoren
Kansen voor Twente Milieu (m.b.t. ondergrondse containers)

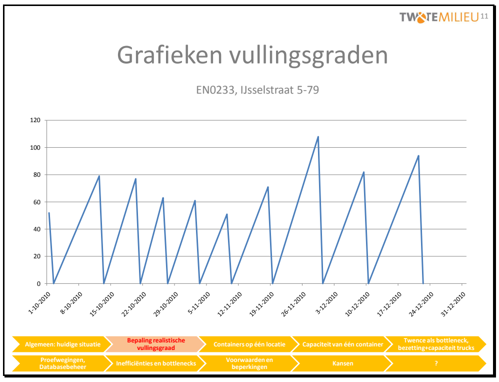

UNIVERSITY OF TWENTE.
TWENTEMILIEU
Problem chart: underground containers
Field of this study
Legend
TWENTEMILIEU


TWENTEMILIEU 7
Underground Container 5m³
Underground Container 4m³
Underground Container 3m³
TWENTEMILIEU
Praktisch
Drie verschillende container volumes (3, 4, 5 m^3)
Verschillende types containers
Alléén inzicht in aantal klepbewegingen
Gemiddelde vullingsgraad van ca. 56%
Veel zwerfafval
Mogelijkheid om te wegen (gebeurt niet vaak)

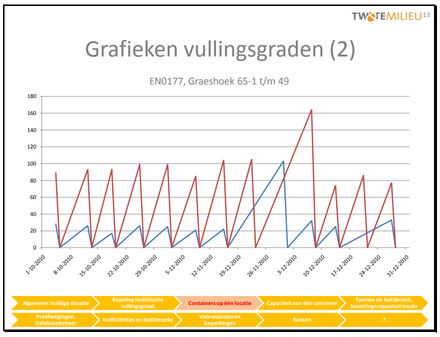

TWENTEMILIEU 8
Organisatorisch
Informatie erg verspreid (data, storingen, etc.)
Onvolledige documentatie
Onduidelijk wie wat doet
Wie is verantwoordelijk?
Geen centrale aansturing

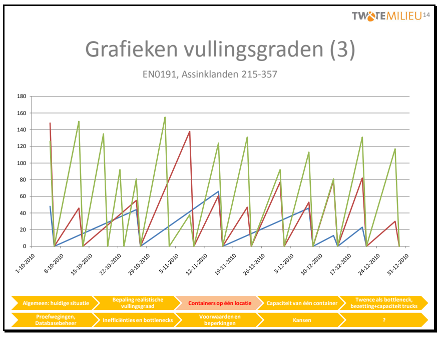

TWENTEMILIEU 9
Realistische bepaling van de vullingsgraad van de ondergrondse containers

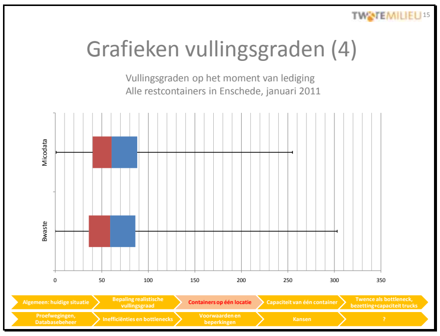

TWENTEMILIEU 10
De werkelijke vullingsgraden liggen ver beneden de vullingsgraden zoals aangegeven in de databases
Vullingsgraden nu alleen gebaseerd op aantal klepbewegingen
Aanname +1% per klepbeweging (Mic-o-data) / capaciteit van 120 zakken (B-waste)
Vullingsgraden lopen daardoor sterk uiteen

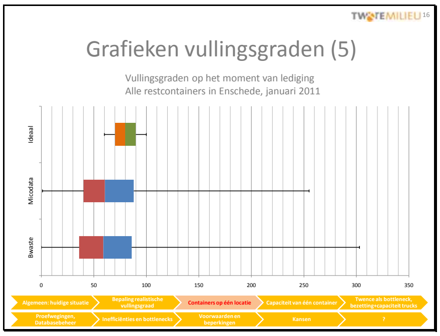

TWENTEMILIEU 11
Grafieken vullingsgraden
EN0233, IJsselstraat 5-79
120
100
80
60
40
20
0
1-10-2010
8-10-2010
15-10-2010
22-10-2010
29-10-2010
5-11-2010
12-11-2010
19-11-2010
26-11-2010
3-12-2010
10-12-2010
17-12-2010
24-12-2010
31-12-2010


TWENTEMILIEU 12
De hoeveelheid containers op één locatie (quota en observaties)

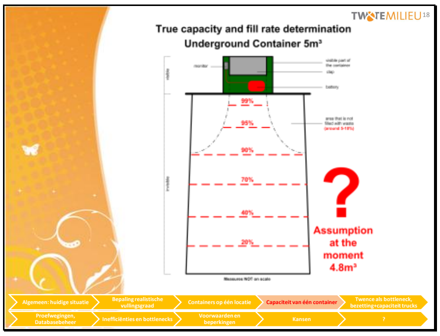

Grafieken vullingsgraden (2)
EN0177, Graeshoek 65-1 t/m 49


Grafieken vullingsgraden (3)
EN0191, Assinklanden 215-357


Grafieken vullingsgraden (4)
Vullingsgraden op het moment van lediging
Alle restcontainers in Enschede, januari 2011
Micodata
Bwaste


Grafieken vullingsgraden (5)
Vullingsgraden op het moment van lediging
Alle restcontainers in Enschede, januari 2011
Ideaal
Micodata
Bwaste

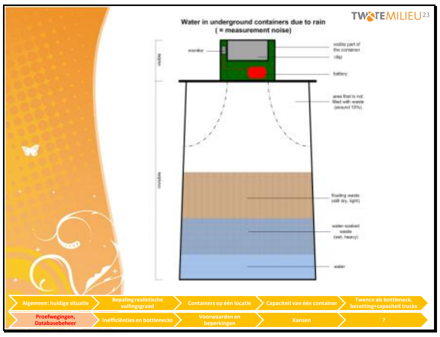

Totale capaciteit van één ondergrondse container (i.v.m. het soortelijk gewicht van het gestorte afval)


True capacity and fill rate determination
Underground Container 5m³
Assumption at the moment 4.8m³

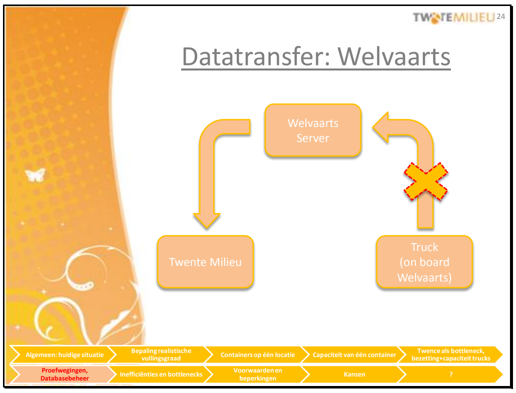

TWENTEMILIEU 19
Soortelijk gewicht verschilt per container
Bij wegen en resetten zit veel menselijk gedrag in → frequentie van fouten is hoger
Voorbeeld: container met verpakkingsmateriaal vs. container met restaurant afval
Op internet: ongesorteerd bedrijfsafval 150 kg / m^3
Nauwkeurig soortelijk gewicht is belangrijk om te bepalen hoe vol een container was toen hij gewogen werd → mogelijkheid om stortingspatronen te verkennen
Algemeen: huidige situatie
Bepaling realistische vullingsgraad
Containers op één locatie
Capaciteit van één container
Twence als bottleneck, bezetting+capaciteit trucks
Proefwegingen, Databasebeheer
Inefficiënties en bottlenecks
Voorwaarden en beperkingen
Kansen
?

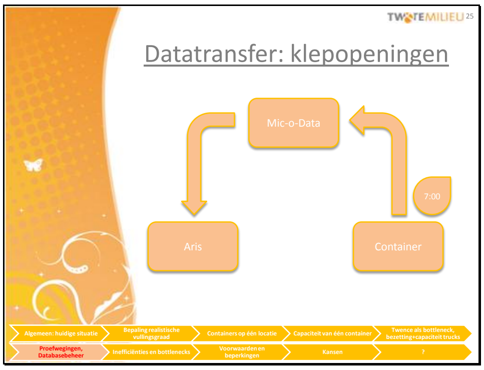

TWENTEMILIEU 22
Proefwegingen en Databasebeheer (wat is waar te vinden, de noodzaak van drie verschillende databases, Welvaarts)
Algemeen: huidige situatie
Bepaling realistische vullingsgraad
Containers op één locatie
Capaciteit van één container
Twence als bottleneck, bezetting+capaciteit trucks
Proefwegingen, Databasebeheer
Inefficiënties en bottlenecks
Voorwaarden en beperkingen
Kansen
?


TWENTEMILIEU 20
Twence als potentiële bottleneck van de operaties van Twente Milieu, bezettingsgraad en capaciteit van trucks
Algemeen: huidige situatie
Bepaling realistische vullingsgraad
Containers op één locatie
Capaciteit van één container
Twence als bottleneck, bezetting+capaciteit trucks
Proefwegingen, Databasebeheer
Inefficiënties en bottlenecks
Voorwaarden en beperkingen
Kansen
?


TWENTEMILIEU 23
Water in underground containers due to rain
(= measurement noise)
Algemeen: huidige situatie
Bepaling realistische vullingsgraad
Containers op één locatie
Capaciteit van één container
Twence als bottleneck, bezetting+capaciteit trucks
Proefwegingen, Databasebeheer
Inefficiënties en bottlenecks
Voorwaarden en beperkingen
Kansen
?


TWENTEMILIEU 21
Nu: bezetting vrachtwagen 8/(12+2)=0.57 (Twence open van 7 tot 7, vracht- wagen wordt leeg geparkeerd)
daadwerkelijke capaciteit van een vrachtwagen (90000L? → van welk soortelijk gewicht wordt er uitgegaan? σ?)
Algemeen: huidige situatie
Bepaling realistische vullingsgraad
Containers op één locatie
Capaciteit van één container
Twence als bottleneck, bezetting+capaciteit trucks
Proefwegingen, Databasebeheer
Inefficiënties en bottlenecks
Voorwaarden en beperkingen
Kansen
?


TWENTEMILIEU 24
Datatransfer: Welvaarts
Welvaarts Server
Twente Milieu
Truck (on board Welvaarts)
Algemeen: huidige situatie
Bepaling realistische vullingsgraad
Containers op één locatie
Capaciteit van één container
Twence als bottleneck, bezetting+capaciteit trucks
Proefwegingen, Databasebeheer
Inefficiënties en bottlenecks
Voorwaarden en beperkingen
Kansen
?

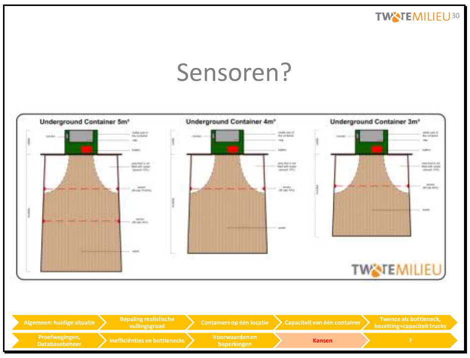

Datatransfer: klepopeningen
Mic-o-Data
7:00
Aris
Container

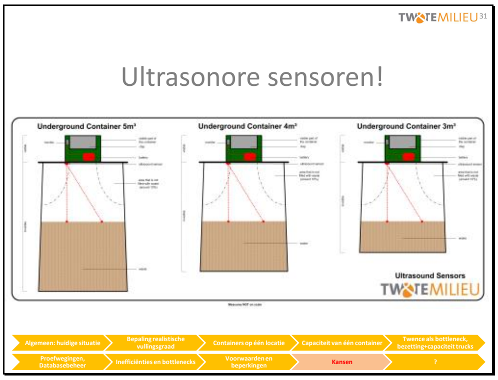

Voorwaarden en beperkingen van de huidige operaties, verstoringsfactoren


Nu: twee verschillende databases
Communicatieprobleem tussen Welvaarts en Twente Milieu
Barcodesysteem werkt niet foutloos; omslachtig

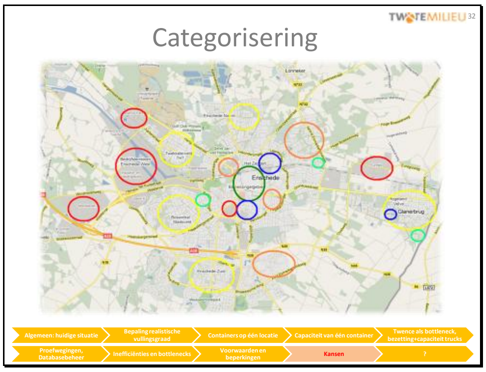

Kansen voor Twente Milieu (m.b.t. ondergrondse containers)


Zoektocht naar inefficiënties en bottlenecks


Sensoren?
Underground Container 5m³
Underground Container 4m³
Underground Container 3m³


Ultrasonore sensoren!
Underground Container 5m³
Underground Container 4m³
Underground Container 3m³
Ultrasound Sensors
TWENTEMILIEU


Discussie:
Hoe nu verder?
Capaciteiten?
Groepslegingen?
Aantal containers op één locatie?
Sensoren?
Representatieve categorisering?
Hoe kan de coördinatie beter?
Hoe kunnen fouten m.b.t. Resetten en wegen voorkomen worden?
Twence als bottleneck?


Categorisering


?


Per groep legen
Huishoudens beter indelen op groepen van containers
(voor een betere spreiding)


Bedankt voor jullie aandacht!

Appendix 5 – Interviews at Twente Milieu

Interview 1:
Location manager Hengelo /
Executive director underground containers

- One central coordination necessary
- True capacity and fill behavior of containers unknown at the moment
- No wide-spread data about weights of containers available
- Mic-o-Data and B-waste containers have own software, not integrated into one package yet
- 5, 4, 3 m^3 containers used (due to cables in the ground)
- Responsibilities w.r.t. underground containers not always clear
- Law: 75 meter maximum distance for walking to a container, execptions: maximum 125 meter (no further extension possible so far)
- Groups of containers: possibilities available to change access to containers w.r.t. citizen access-cards
- Barcode-system does not work properly always
- Problems with manual resetting of containers
- (confidential topics…)

Interview 2:
Employee maintenance underground containers

- Steel used in B-waste containers is inferior → abrasion already visible after short-term usage
- Housing is corroding rather fast
- Water is many pits present (e.g. Begoniastraat), reasons:
    - Placed to low w.r.t. surroundings
    - New pavement surface
    - Assembly mistakes: forgotten rubber layer (e.g. Assinklanden)
- Operating buttons often defect
- Displays unreadable due to condensed water behind the cover layer
- Batteries already discharged after few months instead of two years
- Maintenance service:
    - not much information available over failure → no central database about container properties existent → time lost due to uncertainty in needed tools and spare parts
    - all the different maintenance services get a failure alarm → alarm is not specific enough (e.g. electrical, mechanical failure, etc.)
- Containers sometimes not placed very logically → difficult to reach with the crane truck (chance of overturn of trucks when containers are full)
- Four generations of containers used

- no extensive data registration about failures, no easily comprehensible database existent (if documentation is available then mostly only as a paper version)
- central failure coordination needed (also w.r.t. material procurement)
- often high bureaucratic efforts necessary for different municipalities (municipalities do not always react very fast on failures and repair necessities, every communal entity has its own set of rules)
- containers that are placed improperly break down faster (human behavior (e.g. nervousness) involved → driver try to avoid collisions with surroundings (e.g. cars)
- price B-waste containers: ca. € 4200
- price Bammers container: ca. € 8000
- containers especially in Enschede vulnerable for water damage
- collecting waste based on fill rate derived from clap openings:
  worked for two weeks, then it failed
- more waste at the begin of a month (people get their salaries at that time and thus spend more than during the thrifty time at the end of a month)
- disposals are often smaller in the summer, since they stink earlier
- problems with fill rate were already noticeable one and a half years ago
- ultrasound sensors have been discussed in an earlier stage
- too many containers at one location: solution alternative → installment of access unit in a pillar instead of on each container → will better ensure a even distribution of waste among the containers
- dynamic routing only interesting for location emptying instead of individual container emptying
- In Hengelo it might be possible to collect waste until 23:00 at night
- Even correctly performed resets are not communicated to the AWRS server
- Not much data collected about glass and plastic collection
- A lot of changes in management → responsibilities not always clear for everybody
- Weighing system does not always work as It is supposed to
- Laptop in service truck necessary
- (confidential topics…)

INTERVIEW 3:
DRIVER FOR UNDERGROUND CONTAINERS

- Trustworthiness of historical weight data is not very high (e.g. container was broken a long time and residents did not know that when it was repaired again → they did not use the container since they thought it still would be broken, or a container does not fill very fast, since half of the residents do not even have an access card for that particular container)
- Two block containers represent one underground container
- Often failures w.r.t. the access system of containers
- There is no need for a fixed route through the city centers
- Container weight is relative, because of water leakages the waste becomes heavier
- Weighing system breaks down quite often (often no connection between trucks (Welvaarts) and AWRS servers possible) → weighing is not consistent
- Weighing procedure takes ca. 1.5 hours per day extra → very time consuming
- Normally drivers check whether containers work or not → if not, they call the maintenance department
- Barcode system is not very convenient for drivers, since it takes too much time → weighing per location would be preferred
- Disposal claps often fail
- Environmental police does not have a lot of power
- Weighing directly after lifting a container → most stabile results
- Deppenbroek, Stroiklanden, Twekkelerveld: a lot of illegal disposals (next to the containers)
- City center is only between 7:00 and 11:00 in the morning well reachable, later is becomes to dense with pedestrians, residents and entrepreneurs
- On average 60-70contaiers possible to collect per day
- Null-measurements are not always a mistake → sometimes containers are simply empty
- Thursday is the busiest day in the city centers
- There are apparently not enough people in the maintenance team → they are too spread out among various tasks
- Trucks approximately full after 20-25 containers (8-9 tons)\
- new containers (B-waste) wear out quite fast
- Measurement distortion:
    - due to time constraints, drivers weigh several containers with only one barcode (even if they do not belong to that code) → measurements become invalid
    - altitude measurement: waste floats on water, if there is water in a container pit – however this effect becomes less severe the higher the waste is stapled
- Holidays distort the disposal pattern
- (confidential topics…)

Other Interviews:

- Battery: 18 Volt, recharge ate 4 Volt
- Problem with locking mechanism of a lot of containers: containers can be re-opened within 5-10 seconds (buzz-sound audible)
- Ultrasound sensors have problems with different kinds of waste → sound waves get absorbed → proposition: radar sensors
- Maximum extension of containers within Twente Milieu: 1500 pieces
- Water in containers is very unpleasant, since municipalities pay per kilogram waste disposed at Twence → heavy, watery waste is more expensive than dry one
- Costs of one truck: ca. € 300000
- (confidential topics…)

APPENDIX 6 – NOTES ABOUT FIELD TRIPS

Bevindingen met het legen van ondergrondse containers wo 23-02-2011
Arnout Dam

Gegevens

Datum	Ma 21-02	Di 22-02
Chauffeur	Richard Wagenaar	Erik Helthuis
Kenteken	BT-ZV-15	BX-VT-43
Type	Oud	Nieuw
Rit 1 - route	43 containers	51 containers
	10260 kg	9620 kg
Rit 2	20 containers	19 containers
	4220 kg	4000 kg
Gebied	Centrum, Zuid	West, Noord
Totaal	63 containers	70 containers
	14480 kg	13620 kg

Totaal aantal geleegde containers	133
Totaal aantal gewogen containers	115
Totaal aantal geresette containers	123

→ probleem handmatig!

Bevindingen

De wagen van Richard is oud (met grote grijze bak achter). De wagen van Erik is nieuw (wit met TM logo), kleiner en wendbaarder, maar er past net zoveel in. Beide wagens zijn uitgerust met Welvaarts weegsysteem. Het verschil zit in de manier waarop de kraan is geplaatst in rust. Bij de oude wagen steunt de kraan op de wagen, waardoor er wel iets gewogen wordt, ondanks dat er niks aan de kraan hangt. Bij de nieuwe wagen hangt de kraan vrij in de wagen, hierdoor geeft het systeem een negatief gewicht aan. Bij de oude wagen vallen de gewichten dus hoger uit dan bij de nieuwe, maar netto komen ze wel overeen.

→ wagens wegen verschillend

Veel containers zijn lang niet vol op het moment van legen, hier valt dus nog veel winst te behalen. Momenteel worden er nog vaste routes gereden, maar volgens Erik wordt er in Hengelo al wel gereden op vullingsgraad (is aantal klepbewegingen).

De chauffeurs zijn over het algemeen negatief over het rijden op vullingsgraad. De voordelen zijn niet duidelijk. Ook ontbreken de middelen hiervoor, zoals scanlijsten op de wagen of een draadloze scanner. Met de vaste routes weet de chauffeur dat hij alle containers bij langs gaat; hij kent de route en kan vrij goed inschatten welke container vol zal zijn.

→ c. [illegible] op het kantoor (werkvoorbereiding niet goed bereikbaar) ⇓ er wordt niet genoeg naar de werkvloer geluisterd

De communicatie verloopt niet goed. Voor de chauffeurs verandert er vaak iets en meestal zien ze er het nut niet van in en voeren ze maar gewoon uit waardoor ze minder plezier in hun werk hebben. De chauffeurs verdelen vaak onderling de containers.

Het wegen verloopt nog niet echt soepel. Het systeem in de wagen werkt meestal wel (als er een volle batterij in zit), maar moet even opwarmen (maandagochtend kon er geen verbinding gemaakt worden). Voor de Mic-o-data containers in de binnenstad liggen scanlijsten in de wagen, maar voor de overige containers in de stad niet. De Bwaste containers konden we wel wegen door het REN-nummer met de hand in te toetsen. Dit kost echter teveel tijd als de chauffeur alleen is. Ook moet de chauffeur vaak heen en weer lopen tussen de wagen en de container, wat ook veel tijd kost.

Van de meeste containers konden we de gewichten noteren. In een enkel geval gaf het systeem een dubbele weging aan en kregen we een netto nulgewicht. Het is belangrijk dat de container enige tijd stil hangt. De gewichten worden echter niet doorgegeven aan de Welvaarts database. Er wordt zelfs niks doorgegeven. Waarschijnlijk komt dat omdat het systeem te vroeg wordt uitgeschakeld.

Er ligt geregeld afval naast de containers, ook als die nog niet vol zitten. De chauffeurs verwachten dat dit alleen maar zal toenemen als diftar wordt ingevoerd en de burgers dus moeten betalen. Hier zijn in Hengelo negatieve ervaringen mee.

Op locaties waar meerdere containers staan, is er vaak maar één vol. Er staan dus ofwel teveel containers, of ze worden te vaak geleegd. Daarbij gaan burgers vaak bellen als er één containers vol is, terwijl in de andere nog genoeg ruimte zit. → aan het telefoon advies geven om andere container te gebruiken

Conclusies (wat betreft het wegen)

Er kan momenteel gewogen worden, maar dit kost teveel tijd. Dit kan opgelost worden door bijvoorbeeld: draadloze scanners en scanlijsten van alle containers (op volgorde) in de wagen of beter: een chip in de container die zodra de kraan de container optilt, de container reset en begint met wegen zodat er helemaal niet meer gescand hoeft te worden.

De gewichten worden nog niet doorgegeven aan de server van Welvaarts (De routes stonden er zelfs helemaal niet in). Waarschijnlijk komt dit omdat het systeem te vroeg wordt uitgeschakeld. Dit kan getest worden door de computer in de wagen aan te laten staan aan het eind van de dag.

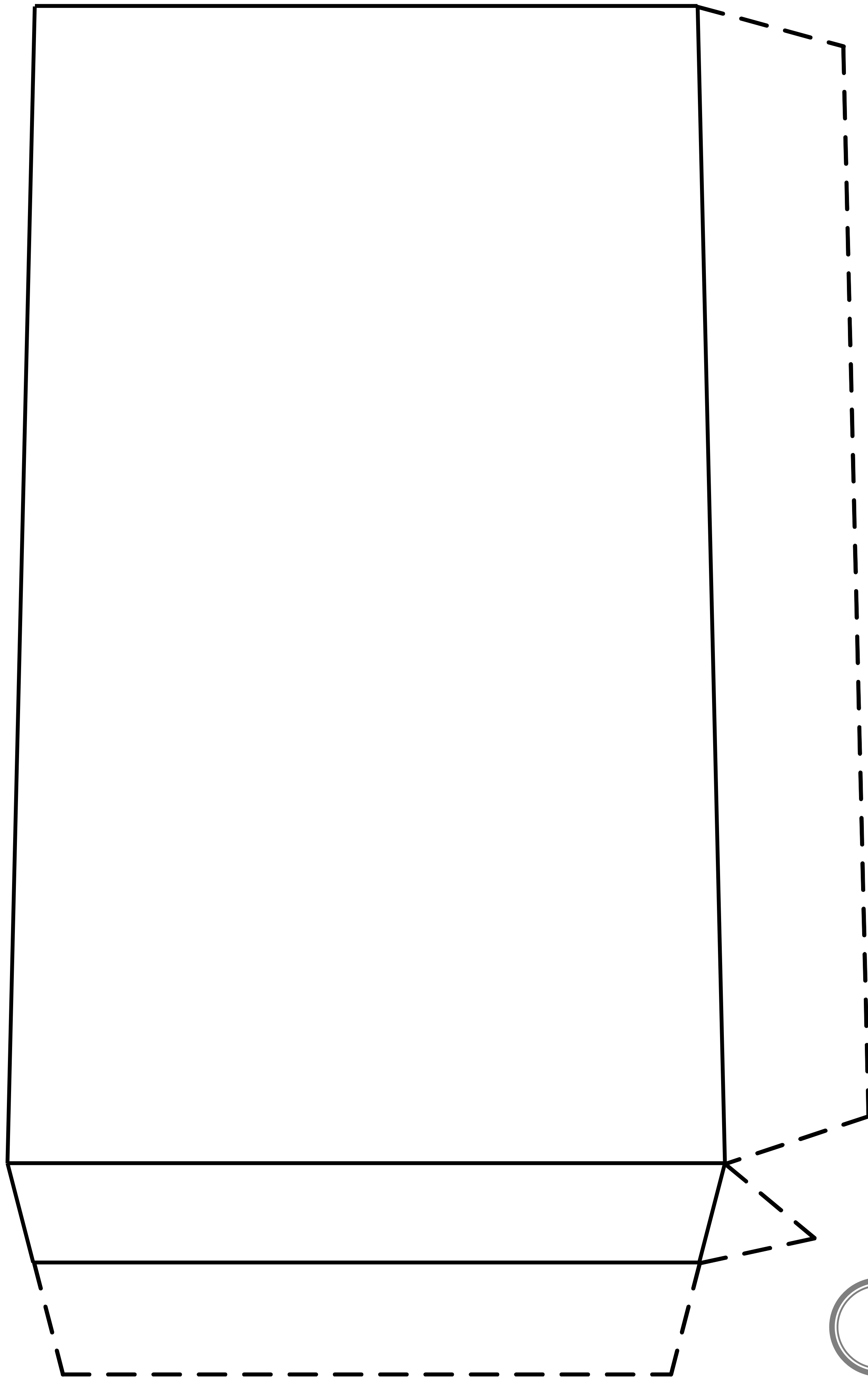
APPENDIX 7 – 5M^3 CONTAINER MODEL (SCALE 1:10.4)

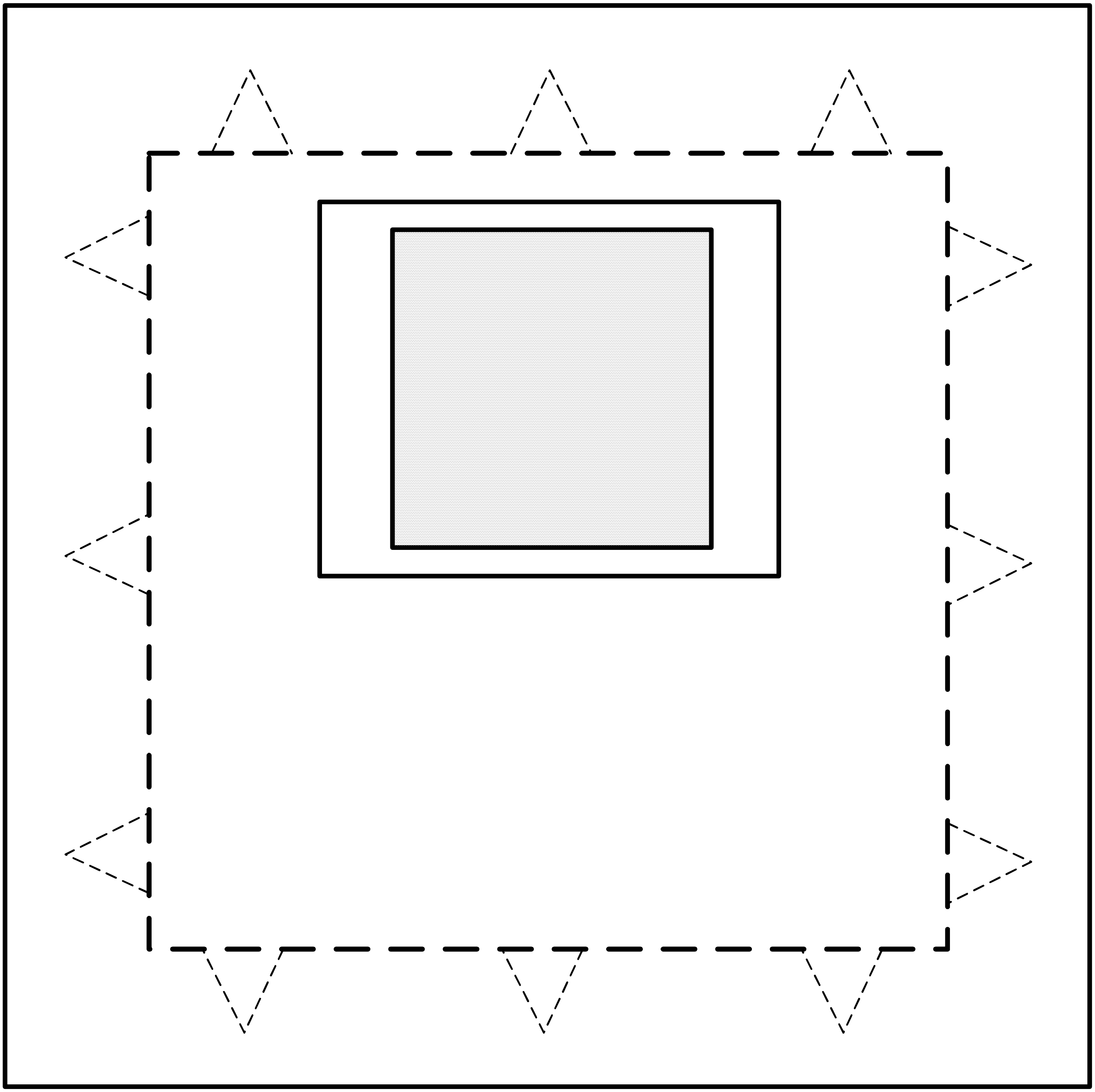
Content:

1 x side cover

1 x top cover with fill chute

1 x bottom cover





APPENDIX 8
– WASTE VOLUME DETERMINATION (ALTITUDE IN CM, VOLUME IN M^3)

Volume determination of container filling based on altitude of waste

assumption: total of usable volume is: 3,93 m^3 (21% lost volume due to pyramid-like fill process)

altitude in cm	distance from ultrasound sensor in cm	Volume (with solid waste) in % (fill rate approximation)	Volume (with solid waste) in m^3 (for truck capacity calculations)
0	253	0,00%	0,00
1	252	0,36%	0,01
2	251	0,72%	0,03
3	250	1,09%	0,04
4	249	1,45%	0,06
5	248	1,82%	0,07
6	247	2,19%	0,09
7	246	2,57%	0,10
8	245	2,94%	0,12
9	244	3,32%	0,13
10	243	3,70%	0,15
11	242	4,08%	0,16
12	241	4,46%	0,18
13	240	4,85%	0,19
14	239	5,24%	0,21
15	238	5,62%	0,22
16	237	6,02%	0,24
17	236	6,41%	0,25
18	235	6,81%	0,27
19	234	7,21%	0,28
20	233	7,61%	0,30
21	232	8,01%	0,32
22	231	8,41%	0,33
23	230	8,82%	0,35
24	229	9,23%	0,36
25	228	9,64%	0,38
26	227	10,05%	0,40
27	226	10,47%	0,41
28	225	10,89%	0,43
29	224	11,31%	0,45
30	223	11,73%	0,46
31	222	12,16%	0,48

32	**221**	12,58%	**0,50**
33	**220**	13,01%	**0,51**
34	**219**	13,40%	**0,53**
35	**218**	13,81%	**0,54**
36	**217**	14,22%	**0,56**
37	**216**	14,64%	**0,58**
38	**215**	15,05%	**0,59**
39	**214**	15,46%	**0,61**
40	**213**	15,88%	**0,62**
41	**212**	16,29%	**0,64**
42	**211**	16,70%	**0,66**
43	**210**	17,12%	**0,67**
44	**209**	17,53%	**0,69**
45	**208**	17,94%	**0,71**
46	**207**	18,35%	**0,72**
47	**206**	18,77%	**0,74**
48	**205**	19,18%	**0,75**
49	**204**	19,59%	**0,77**
50	**203**	20,00%	**0,79**
51	**202**	20,41%	**0,80**
52	**201**	20,82%	**0,82**
53	**200**	21,24%	**0,84**
54	**199**	21,65%	**0,85**
55	**198**	22,06%	**0,87**
56	**197**	22,47%	**0,88**
57	**196**	22,88%	**0,90**
58	**195**	23,29%	**0,92**
59	**194**	23,70%	**0,93**
60	**193**	24,11%	**0,95**
61	**192**	24,52%	**0,96**
62	**191**	24,93%	**0,98**
63	**190**	25,34%	**1,00**
64	**189**	25,75%	**1,01**
65	**188**	26,15%	**1,03**
66	**187**	26,56%	**1,05**
67	**186**	26,97%	**1,06**
68	**185**	27,38%	**1,08**
69	**184**	27,79%	**1,09**
70	**183**	28,20%	**1,11**
71	**182**	28,60%	**1,13**
72	**181**	29,01%	**1,14**
73	**180**	29,42%	**1,16**
74	**179**	29,83%	**1,17**
75	**178**	30,23%	**1,19**
76	**177**	30,64%	**1,21**
77	**176**	31,05%	**1,22**
78	**175**	31,45%	**1,24**
79	**174**	31,86%	**1,25**
80	**173**	32,27%	**1,27**
81	**172**	32,67%	**1,29**
82	**171**	33,08%	**1,30**
83	**170**	33,49%	**1,32**

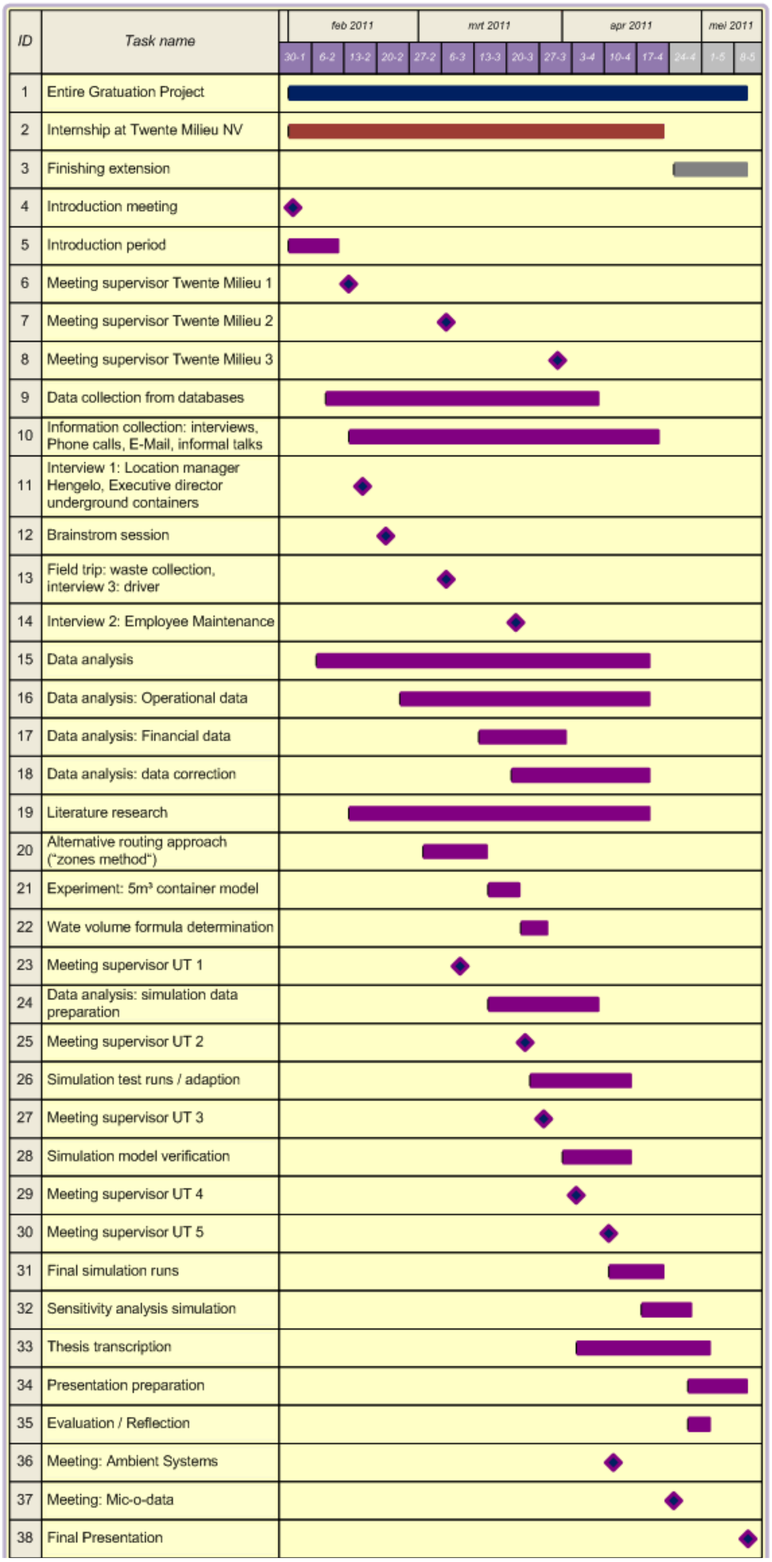
84	169	33,89%	1,33
85	168	34,30%	1,35
86	167	34,70%	1,37
87	166	35,11%	1,38
88	165	35,51%	1,40
89	164	35,92%	1,41
90	163	36,32%	1,43
91	162	36,73%	1,45
92	161	37,13%	1,46
93	160	37,53%	1,48
94	159	37,94%	1,49
95	158	38,34%	1,51
96	157	38,75%	1,52
97	156	39,15%	1,54
98	155	39,55%	1,56
99	154	39,96%	1,57
100	153	40,36%	1,59
101	152	40,76%	1,60
102	151	41,16%	1,62
103	150	41,57%	1,64
104	149	41,97%	1,65
105	148	42,37%	1,67
106	147	42,77%	1,68
107	146	43,17%	1,70
108	145	43,58%	1,71
109	144	43,98%	1,73
110	143	44,38%	1,75
111	142	44,78%	1,76
112	141	45,18%	1,78
113	140	45,58%	1,79
114	139	45,98%	1,81
115	138	46,38%	1,83
116	137	46,78%	1,84
117	136	47,18%	1,86
118	135	47,58%	1,87
119	134	47,98%	1,89
120	133	48,38%	1,90
121	132	48,78%	1,92
122	131	49,18%	1,94
123	130	49,58%	1,95
124	129	49,98%	1,97
125	128	50,38%	1,98
126	127	50,77%	2,00
127	126	51,17%	2,01
128	125	51,57%	2,03
129	124	51,97%	2,05
130	123	52,37%	2,06
131	122	52,76%	2,08
132	121	53,16%	2,09
133	120	53,56%	2,11
134	119	53,96%	2,12
135	118	54,35%	2,14

136	117	54,75%	2,15
137	116	55,15%	2,17
138	115	55,54%	2,19
139	114	55,94%	2,20
140	113	56,33%	2,22
141	112	56,73%	2,23
142	111	57,13%	2,25
143	110	57,52%	2,26
144	109	57,92%	2,28
145	108	58,31%	2,29
146	107	58,71%	2,31
147	106	59,10%	2,33
148	105	59,50%	2,34
149	104	59,89%	2,36
150	103	60,29%	2,37
151	102	60,68%	2,39
152	101	61,07%	2,40
153	100	61,47%	2,42
154	99	61,86%	2,43
155	98	62,26%	2,45
156	97	62,65%	2,47
157	96	63,04%	2,48
158	95	63,43%	2,50
159	94	63,83%	2,51
160	93	64,22%	2,53
161	92	64,61%	2,54
162	91	65,01%	2,56
163	90	65,40%	2,57
164	89	65,79%	2,59
165	88	66,18%	2,60
166	87	66,57%	2,62
167	86	66,96%	2,64
168	85	67,36%	2,65
169	84	67,75%	2,67
170	83	68,14%	2,68
171	82	68,53%	2,70
172	81	68,92%	2,71
173	80	69,31%	2,73
174	79	69,70%	2,74
175	78	70,09%	2,76
176	77	70,48%	2,77
177	76	70,87%	2,79
178	75	71,26%	2,80
179	74	71,65%	2,82
180	73	72,04%	2,83
181	72	72,43%	2,85
182	71	72,82%	2,87
183	70	73,20%	2,88
184	69	73,59%	2,90
185	68	73,98%	2,91
186	67	74,37%	2,93
187	66	74,76%	2,94

188	65	75,15%	2,96
189	64	75,53%	2,97
190	63	75,92%	2,99
191	62	76,31%	3,00
192	61	76,70%	3,02
193	60	77,08%	3,03
194	59	77,47%	3,05
195	58	77,86%	3,06
196	57	78,24%	3,08
197	56	78,63%	3,09
198	55	79,02%	3,11
199	54	79,40%	3,12
200	53	79,79%	3,14
201	52	80,17%	3,16
202	51	80,56%	3,17
203	50	80,94%	3,19
204	49	81,33%	3,20
205	48	81,71%	3,22
206	47	82,10%	3,23
207	46	82,48%	3,25
208	45	82,87%	3,26
209	44	83,25%	3,28
210	43	83,64%	3,29
211	42	84,02%	3,31
212	41	84,41%	3,32
213	40	84,79%	3,34
214	39	85,17%	3,35
215	38	85,56%	3,37
216	37	85,94%	3,38
217	36	86,32%	3,40
218	35	86,71%	3,41
219	34	87,09%	3,43
220	33	87,47%	3,44
221	32	87,85%	3,46
222	31	88,24%	3,47
223	30	88,62%	3,49
224	29	89,00%	3,50
225	28	89,38%	3,52
226	27	89,76%	3,53
227	26	90,14%	3,55
228	25	90,52%	3,56
229	24	90,91%	3,58
230	23	91,29%	3,59
231	22	91,67%	3,61
232	21	92,05%	3,62
233	20	92,43%	3,64
234	19	92,81%	3,65
235	18	93,19%	3,67
236	17	93,57%	3,68
237	16	93,95%	3,70
238	15	94,33%	3,71
239	14	94,71%	3,73

240	**13**	95,09%	**3,74**
241	**12**	95,46%	**3,76**
242	**11**	95,84%	**3,77**
243	**10**	96,22%	**3,79**
244	**9**	96,60%	**3,80**
245	**8**	96,98%	**3,82**
246	**7**	97,36%	**3,83**
247	**6**	97,74%	**3,85**
248	**5**	98,11%	**3,86**
249	**4**	98,49%	**3,88**
250	**3**	98,87%	**3,89**
251	**2**	99,25%	**3,91**
252	**1**	99,62%	**3,92**
253	**0**	100,00%	**3,94**

Appendix 9 – Activities at Twente Milieu



Appendix 10 – Waste volume determination for Dutch Excel

Used Excel formula for waste volume in m3

(given the altitude of waste, height of "lost area"-top partial pyramid, length of top side of "lost area"-top partial pyramid; for a *DUTCH (!) Office 2007 Package*)

```
=(ALS((hW-(hT/Mh*hW))<= hB;(1/3)*(hW-(hT/Mh*hW))*( dNoB ^2+ dNoB *(ALS((hW-(hT/Mh*hW))<= hB;
dNoB +(2*(hW-(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((hW-(hT/Mh*hW))<= hB; dNoB
+(2*(hW-(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000;((1/3)*((hW-(hT/Mh*hW))-
hB)*( dWithB ^2+ dWithB *(ALS((hW-(hT/Mh*hW))<= hB; dNoB +(2*(hW-
(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((hW-(hT/Mh*hW))<= hB; dNoB
+(2*(hW-(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000)+((1/3)* hB *( dNoB ^2+ dNoB
* dWithB + dWithB ^2)/1000000)))+((1/3)*(hT/Mh*hW)*(sT^2+sT*(ALS((hW-hT/Mh*hW)<= hB; dNoB
+(2*(hW-hT/Mh*hW)*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))))); dWithB -(2*(hW-
hT/Mh*hW)/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((hW-hT/Mh*hW)<= hB; dNoB +(2*(hW-
hT/Mh*hW)*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))))); dWithB -(2*(hW-
hT/Mh*hW)/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000)
```

INPUT:

hW	→	altitude of waste inside the container in cm
hT	→	initial altitude of top partial pyramid if container is completely full in cm (related to lost area due to pyramid/like fill process, still has to be verified with experiments in real containers(!))
sT	→	length of top side of top partial pyramid in cm (default: 40cm)
Mh	→	maximal height of the usable inner container area (default: 253cm for 5m^3 containers)
dB	→	distance of bulge with respect to the a pure cuboid-like container (default: 5,hB5cm for 5 m^3 containers)
hB	→	Height of bulge with respect to the soil (default: 20cm for 5 m^3 containers)
dNoB	→	length of a container side at the top (or the bottom) *without* taking the bulge into consideration (default: 134cm for 5 m^3 containers)
dWithB	→	length of a container side at the top (or the bottom) taking the bulge into consideration (default: 145cm for 5 m^3 containers)

Used Excel formula for container fill rate in %

(given altitude of waste, height of "lost area"-top partial pyramid, length of top side of "lost area"-top partial pyramid; for a *DUTCH (!) Office 2007 Package*)

```
=100*(((ALS((hW-(hT/Mh*hW))<=hB;(1/3)*(hW-(hT/Mh*hW))*( dNoB ^2+ dNoB *(ALS((hW-(hT/Mh*hW))<= hB; dNoB
+(2*(hW-(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((hW-(hT/Mh*hW))<= hB; dNoB +(2*(hW-
(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000;((1/3)*((hW-(hT/Mh*hW))- hB)*( dWithB
^2+ dWithB *(ALS((hW-(hT/Mh*hW))<= hB; dNoB +(2*(hW-(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB /
hB))))); dWithB -(2*(hW-(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((hW-(hT/Mh*hW))<= hB;
dNoB +(2*(hW-(hT/Mh*hW))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*(hW-
(hT/Mh*hW))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000)+((1/3)* hB *( dNoB ^2+ dNoB * dWithB +
dWithB ^2)/1000000)))+((1/3)*(hT/Mh*hW)*(sT^2+sT*(ALS((hW-hT/Mh*hW)<= hB; dNoB +(2*(hW-
hT/Mh*hW)*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*(hW-
hT/Mh*hW)/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((hW-hT/Mh*hW)<= hB; dNoB +(2*(hW-
hT/Mh*hW)*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*(hW-
hT/Mh*hW)/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000))/((ALS((Mh -(hT/Mh* Mh))<= hB;(1/3)*( Mh
-(hT/Mh* Mh))*( dNoB ^2+ dNoB *(ALS((Mh -(hT/Mh* Mh))<= hB; dNoB +(2*( Mh -(hT/Mh*
Mh))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*( Mh -(hT/Mh*
Mh))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((Mh -(hT/Mh* Mh))<= hB; dNoB +(2*( Mh -(hT/Mh*
Mh))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*( Mh -(hT/Mh*
Mh))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000;((1/3)*(( Mh -(hT/Mh* Mh))- hB)*( dWithB ^2+
dWithB *(ALS((Mh -(hT/Mh* Mh))<= hB; dNoB +(2*( Mh -(hT/Mh*v))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB)))));
dWithB -(2*( Mh -(hT/Mh* Mh))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((Mh -(hT/Mh* Mh))<= hB; dNoB
+(2*( Mh -(hT/Mh* Mh))*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*( Mh -(hT/Mh*
Mh))/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000)+((1/3)* hB *( dNoB ^2+ dNoB * dWithB + dWithB
^2)/1000000)))+((1/3)*(hT/Mh* Mh)*(sT^2+sT*(ALS((Mh -hT/Mh* Mh)<= hB; dNoB +(2*( Mh -hT/Mh*
Mh)*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*( Mh -hT/Mh*
Mh)/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))+(ALS((Mh -hT/Mh* Mh)<= hB; dNoB +(2*( Mh hT/Mh*
Mh)*TAN(RADIALEN(GRADEN(BOOGTAN(dB / hB))))); dWithB -(2*( Mh -hT/Mh*
Mh)/TAN(RADIALEN(GRADEN(BOOGTAN(Mh/ dB)))))))^2)/1000000)))
```

INPUT:

hW	→	altitude of waste inside the container in cm
hT	→	initial altitude of top partial pyramid if container is completely full in cm (related to lost area due to pyramid/like fill process, still has to be verified with experiments in real containers(!))
sT	→	length of top side of top partial pyramid in cm (default: 40cm)
Mh	→	maximal height of the usable inner container area (default: 253cm for 5m^3 containers)
dB	→	distance of bulge with respect to the a pure cuboid-like container (default: 5,hB5cm for 5 m^3 containers)
hB	→	Height of bulge with respect to the soil (default: 20cm for 5 m^3 containers)
dNoB	→	length of a container side at the top (or the bottom) *without* taking the bulge into consideration (default: 134cm for 5 m^3 containers)
dWithB	→	length of a container side at the top (or the bottom) taking the bulge into consideration (default: 145cm for 5 m^3 containers)

APPENDIX 11 – ABBREVIATIONS AND DEFINITIONS

List of definitions and abbreviations[1]

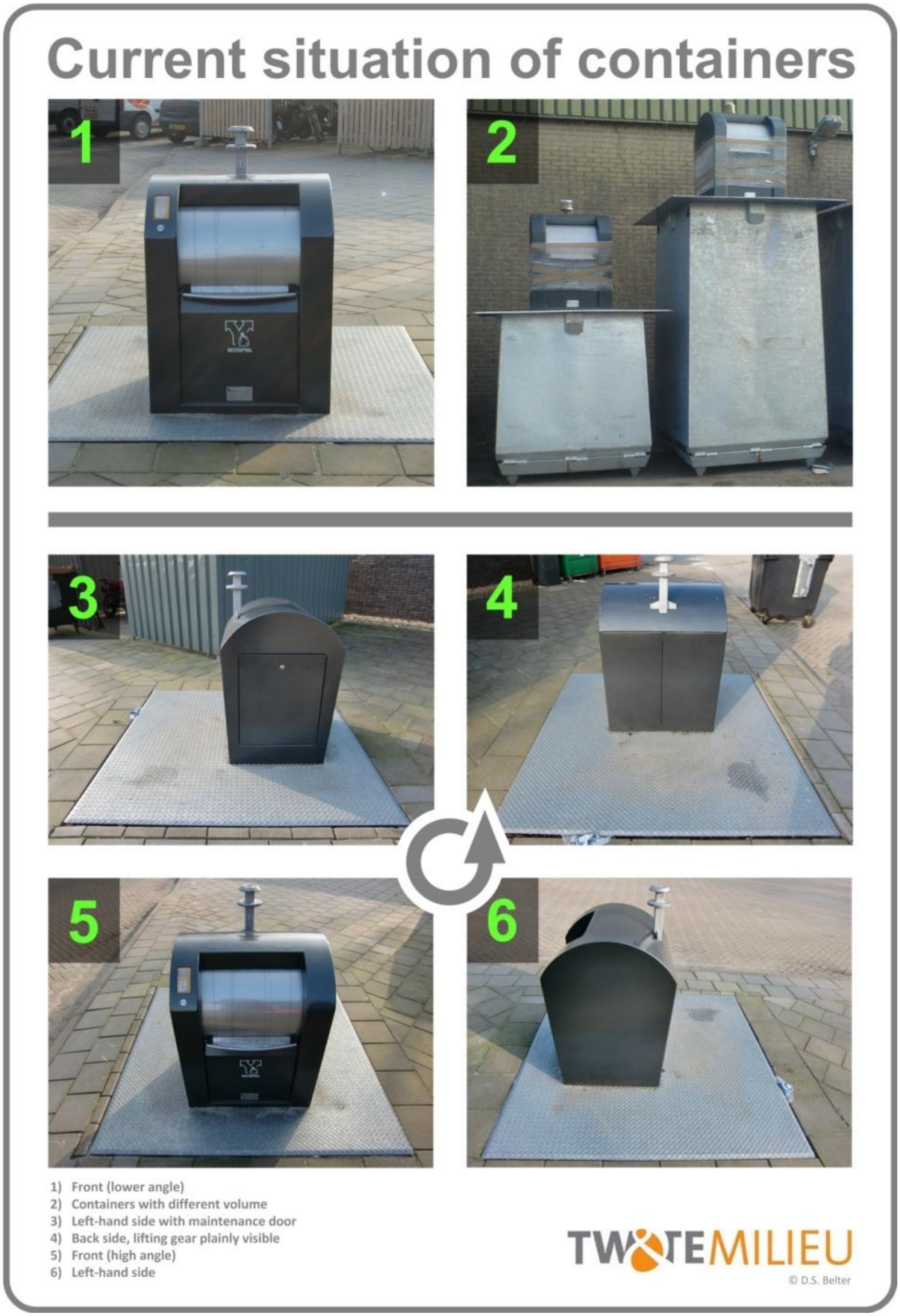
In order to simplify the understanding of the following chapters a list of definitions and abbreviations is presented in this section. It is indented to give the reader a general insight on the terms and speech patterns that will be used throughout the entire report.

- *Underground container / Container:* A container used by multiple households for the disposal of household refuse. The container is dug into the ground in such a way that only the lid is visible.
- *Truck:* A truck is a vehicle that is capable of collecting underground containers. The default capacity of a truck is assumed to be 90,000 liters, which equal approximately 8-9 tons of refusal.
- *Output ratio / fill rate:* The output ratio / fill rate is the ratio of refuse volume to container volume and indicates how full a container is.
- *Calculated output ratio:* This output ratio is calculated based on combination of information from the Twente Milieu databases and the registered amount of waste dumped at Twence, together with the assumption that one cubic meter of refuse weighs 110 kilos.
- *Registered output ratio / clap openings:* This output ratio is based on the databases of Twente Milieu and corresponds to the number of times the container lid was opened. This number thus gives the amount of deposits made to the container.
- *Route:* The entire route of a truck is its schedule for a day. A route may contain several trips to Twence and therefore it may consist of a number of sub-routes.
- *Sub-route:* A sub-route is the route a truck makes along a number of containers and then back to Twence. When developing a new planning methodology, it is important to have a clear understanding of the difference between a static and a dynamic planning. Therefore, we use the following definitions:
  - *Static:* We consider a planning to be static, if it is updated or revised less than once a week. Also a static planning does not use data on output ratios / fill rates.
  - *Dynamic:* A dynamic planning is updated at least once a week or more and uses information on the actual output ratios / fill rates of containers to draw up a planning.
- *Days left:* The Days left is calculated for each container and indicates after how many days a container will be full. The Days left might be different for each container, because it is based on the average number of deposits per day and the average deposit sizes for that specific container.
- *Must-go-day:* The Must-go-day is a non-fixed indicator that describes which containers should at least be emptied on a certain day in the future. If the Must-go-day is for example 2, this means that all containers that have a Days left of 2 or less; thus should be emptied today or tomorrow. The Must-go-day might be adjusted, for example to balance workload over the week.
- *Must-go job:* The must-go job is a container which has a days left equal or less than the Must-go-day. It is the aim to serve all must-go jobs on a certain day. The number of must-go jobs deviates from one day to another.

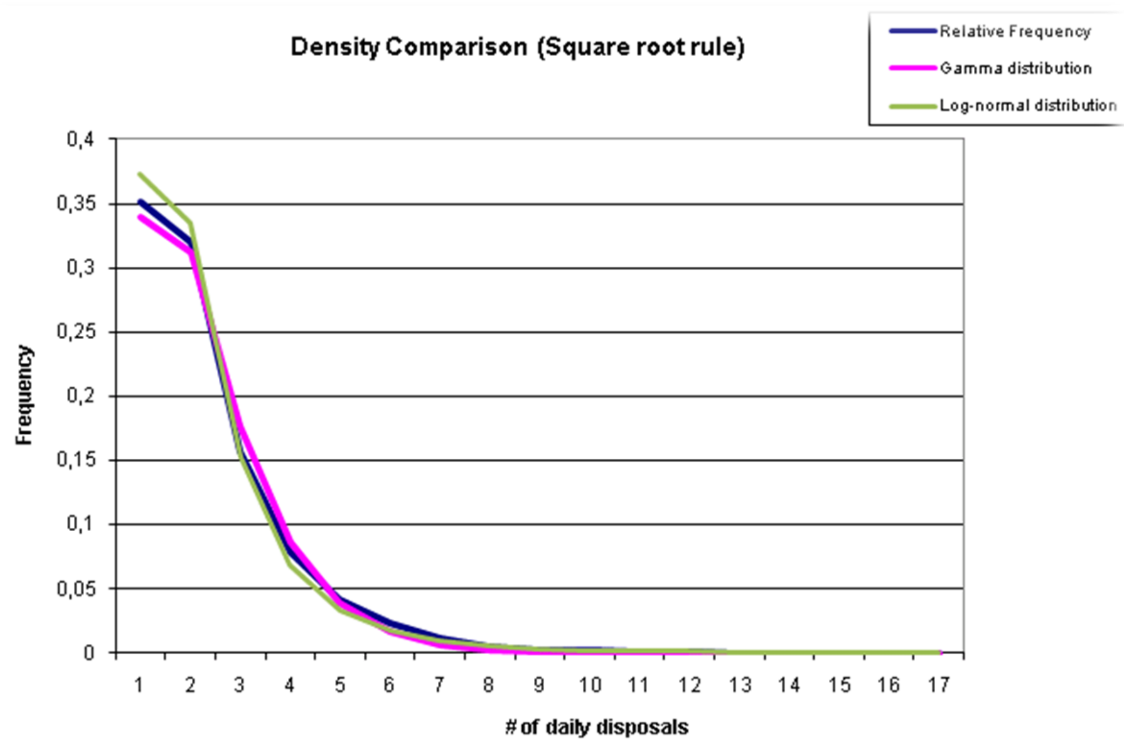
[1] A vast number of the definitions and abbreviations are borrowed from "Dynamic waste collection - Assessing the usage of dynamic routing" (Stellingwerff, 2011), since this research is a follow-up on Stellingswerff's study.

- *May-go day / May-go horizon:* The may-go day indicates how many days it is looked into the future to decide whether a container will be included in a (sub-)route or not. The May-go day is an important parameter for the setting Fixed May-go day in the simulation model.
- *May-go job:* The may-go job is a container that is included in a route after all must-go jobs are planned. May-go jobs are used to increase the occupancy rate and are selected based on their ratio of additional travel time and additional amount of refuse.
- *Sensor:* A Sensor is in our case a level sensor, that enables Twente Milieu to gain more accurate insights on the output ratio / fill rate of their containers used. There are different ways of sensing possible: optical, mechanical, ultrasonic, magnetic, with microwaves or with capacitance. These methods are described in the literature research of this study.
- *Sinus period:* The sinus period is an experimental assumption in the simulation model, that ought to simulate a fluctuating disposal behavior throughout the horizon of the period length. For instance, if the sinus period equals 28 days, it means that in the first 14 days the number of disposals done is higher than the monthly average, while in the last 14 days the opposite is the case. The sinus period is used to simulate the assumed fact that, users dump a larger amount of refuse at the beginning of a month than on the end of it (because a lot of people seem to have more to spend at the beginning of a month than on its end).
- *Work days:* The work days describe the amount of days the waste collection at Twente Milieu is operated during a week. This number can fluctuate between 5 and 6 in our simulation, depending whether it is worked from Monday to Friday or from Monday to Saturday.
- *Seed customer / seed container:* The seed customer / seed container is the first container that is included in a (sub-) route.
- *Clustering:* If clustering is used in the simulation, the (sub-)routes are formed around the chosen seed containers
- *Balancing:* Balancing represents a workload balancing method that is used in the simulation model. Thus if balancing is used, the number of containers that have be emptied from one day to another are smoothed so that their difference becomes smaller. It is the goal of the balancing method to avoid extreme peaks in the daily amount of Must-go-jobs.
- *Rescheduling:* Rescheduling is the possibility to re-plan the containers assigned to a (sub-) route, if turbulences occur during the execution of the waste collection process. There are different ways to tackle the rescheduling issue, which are treated in the literature chapter.
- *Minimum jobs per truck:* A truck only gets send out to collect refusal, if a minimum amount of must-go jobs can be assigned to it, otherwise it will not be considered in the scheduling.
- *Maximum jobs per truck:* A truck is only allowed to handle a certain maximum quantity of must-go and may-go jobs throughout one scheduled (sub-) route.
- *Urgent sorting:* If urgent sorting is used, the must-go jobs are sorted according their priority based on the days left of the individual containers.
- *Variance factor:* The variance factor is applied in the simulation as a multiplier and editor of the disposal volume in order to carry out experiments with different initial situations. The variance factor will be further examined in the chapter focused on the simulation model.

APPENDIX 12 – DEPICTION OF CURRENTLY USED UNDERGROUND CONTAINERS



Appendix 13
– Density comparison deposits per day (square root rule)



Appendix 14 – Test of goodness of fit for distribution of deposits per day

Gamma distribution test

Square Root Rule

Interval (K)	Lower Bound	Upper Bound	Frequency (Nj)	Expected Proportion (Pj)	n*Pj	(Nj-n*Pj)^2 / (n*Pj)
1	1	2	2031	0,038	1980,467726	1,289347302
2	2	3	2632	0,051	2698,399159	1,633875529
3	3	4	3112	0,059	3118,106601	0,011959366
4	4	5	3548	0,063	3326,082099	14,80647602
5	5	6	3562	0,064	3383,51832	9,414966026
6	6	7	3663	0,064	3335,391518	32,17832662
7	7	8	3437	0,061	3215,168011	15,30539962
8	8	9	3250	0,058	3047,792741	13,41553675
9	9	10	2979	0,054	2851,791615	5,674318274
10	10	11	2732	0,050	2640,798168	3,149719788
11	11	12	2391	0,046	2424,725666	0,46909247
12	12	13	2070	0,042	2210,625288	8,945646145
13	13	14	1829	0,038	2003,407107	15,18305427
14	14	15	1639	0,034	1806,32352	15,49952717
15	15	16	1465	0,031	1621,40937	15,08804093
16	16	17	1299	0,028	1449,780134	15,68144601
17	17	18	1114	0,025	1291,8799	24,49241509
18	18	19	972	0,022	1147,675882	26,89088096
19	19	20	890	0,019	1016,793208	15,81100011
20	20	21	791	0,017	898,6298288	12,89093648
21	21	22	721	0,015	792,4382304	6,440149605
22	22	23	615	0,013	697,3876476	9,733072423
23	23	24	597	0,012	612,6086328	0,39769178
24	24	25	542	0,010	537,2287489	0,04237457
25	25	26	454	0,009	470,3933093	0,571310402
26	26	27	440	0,008	411,2829447	2,005114187
27	27	28	360	0,007	359,1237101	0,002138216
28	28	29	365	0,006	313,1933012	8,569576767
29	29	30	282	0,005	272,8241326	0,308611052
30	30	31	295	0,005	237,4041276	13,97315434
31	31	32	282	0,004	206,3758731	27,71161413
32	32	33	211	0,003	179,2346424	5,629703772
33	33	34	201	0,003	155,5256687	13,29629266
34	34	35	187	0,003	134,8409802	20,17608695
35	35	36	183	0,002	116,8158585	37,49782468
36	36	37	151	0,002	101,1255571	24,59773889
37	37	38	121	0,002	87,48156194	12,84254264
38	38	39	138	0,001	75,6283443	51,4386963
39	39	40	114	0,001	65,34011181	36,23784307
40	40	41	91	0,001	56,41778311	21,19774403
41	41	42	89	0,001	48,68617668	33,38122772
42	42	43	81	0,001	41,99142166	36,23762006
43	43	44	53	0,001	36,19859075	7,798296754
44	44	45	57	0,001	31,18954967	21,35905627
45	45	46	48	0,001	26,86101384	16,63588495
46	46	47	38	0,000	23,1228005	9,571983502
47	47	48	35	0,000	19,89626294	11,46561411
48	48	49	45	0,000	17,11289289	45,44472684
49	49	50	28	0,000	14,71307704	11,9990075
50	50	51	31	0,000	12,64499374	26,64344971
51	51	52	22	0,000	10,86363669	11,41593662
52	52	53	30	0,000	9,329952877	45,7934626
53	53	54	13	0,000	8,010083131	3,10849088
54	54	55	28	0,000	6,874694213	64,9161302
55	55	56	15	0,000	5,898392564	14,04437853
56	56	57	13	0,000	5,059210488	12,46363207
57	57	58	15	0,000	4,338156512	26,20350517
58	58	59	15	0,000	3,718822451	34,22184537
59	59	60	10	0,000	3,18704046	14,56411309
60	60	61	7	0,000	2,730584071	6,675462797
61	61	62	6	0,000	2,338907866	5,730706971
62	62	63	11	0,000	2,002921028	40,41468879
63	63	64	8	0,000	1,714790545	23,03713302
64	64	65	4	0,000	1,467770352	4,368658204
65	65	66	6	0,000	1,256053109	17,91726157
66	66	67	8	0,000	1,074641729	44,62937357
67	67	68	6	0,000	0,9192381	28,08210572
68	68	69	5	0,000	0,786146777	22,5868241
69	69	70	1	0,000	0,672191715	0,159862535
70	70	71	1	0,000	0,57464413	0,314851588
71	71	72	3	0,000	0,491160589	12,81510638
72	72	73	1	0,000	0,419729026	0,802218534
73	73	74	1	0,000	0,358622569	1,147069496
74	74	75	4	0,000	0,306359556	44,53257449
75	75	76	5	0,000	0,261669099	85,8021821
76	76	77	3	0,000	0,223461423	34,49886948
77	77	78	4	0,000	0,190802312	76,04722836
78	78	79	1	0,000	0,162891128	4,301960892
79	79	80	0	0,000	0,139041888	0,139041888
80	80	81	5	0,000	0,118666996	200,7922395
81	81	82	2	0,000	0,101263256	35,60226451
82	82	83	0	0,000	0,086399851	0,086399851
83	83	84	1	0,000	0,073708018	11,64075308
84	84	85	1	0,000	0,06287218	13,96815812
85	85	86	0	0,000	0,053622334	0,053622334
86	86	87	0	0,000	0,045727519	0,045727519
87	87	88	1	0,000	0,038990209	23,68645456
88	88	89	0	0,000	0,033241508	0,033241508
89	89	90	1	0,000	0,028337026	33,31785483
90	90	91	0	0,000	0,024153351	0,024153351
91	91	92	0	0,000	0,020585015	0,020585015
92	92	93	0	0,000	0,017541903	0,017541903
93	93	94	0	0,000	0,014947034	0,014947034
94	94	95	0	0,000	0,012734653	0,012734653
95	95	96	0	0,000	0,010848606	0,010848606
96	96	97	2	0,000	0,009240947	428,865297
97	97	98	0	0,000	0,007870742	0,007870742
98	98	99	0	0,000	0,006703048	0,006703048
99	99	100	0	0,000	0,005708044	0,005708044
100	100	101	0	0,000	0,004860283	0,004860283
101	101	102	0	0,000	0,00413805	0,00413805
102	102	103	0	0,000	0,003522822	0,003522822
		Total	52520			96,8799253 test statistic

H0: the Xi's are independent, identically distributed random variables with distribution function F(x)

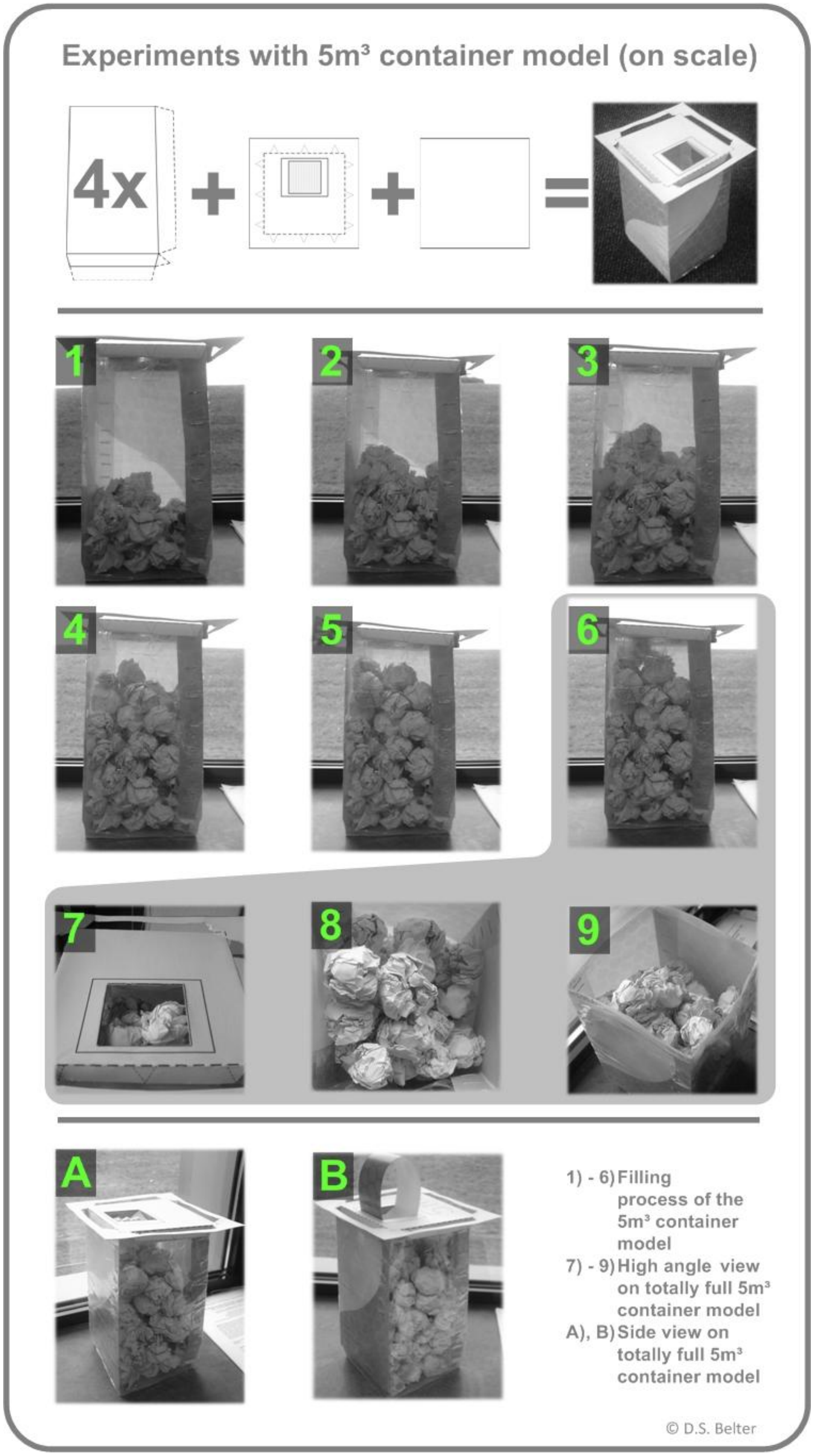
chi^2>chi^2(k-1),1-a	**125,458**
a=0.05	
	test statistic 96,880

Do not reject H0

CONCLUSION

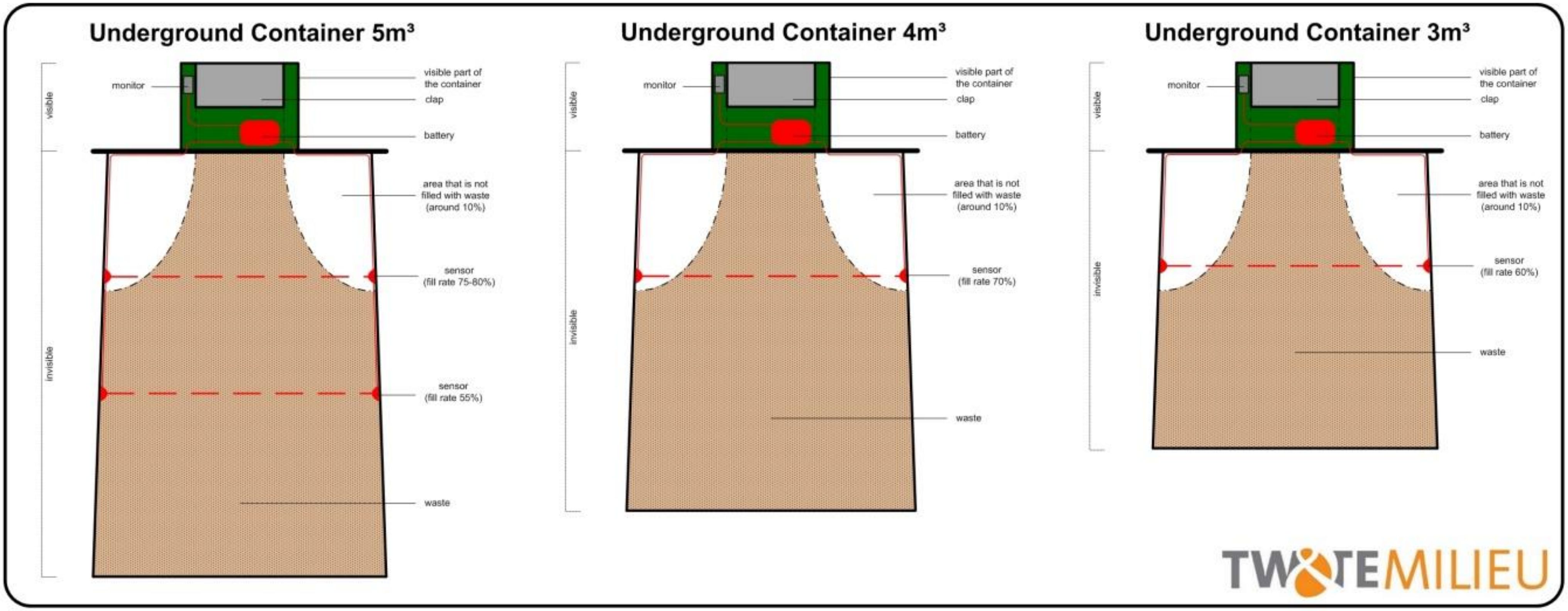
The H0 that our input distribution behavas like a Gamma Distribution IS NOT rejected

Appendix 15 – Container experiment set-up

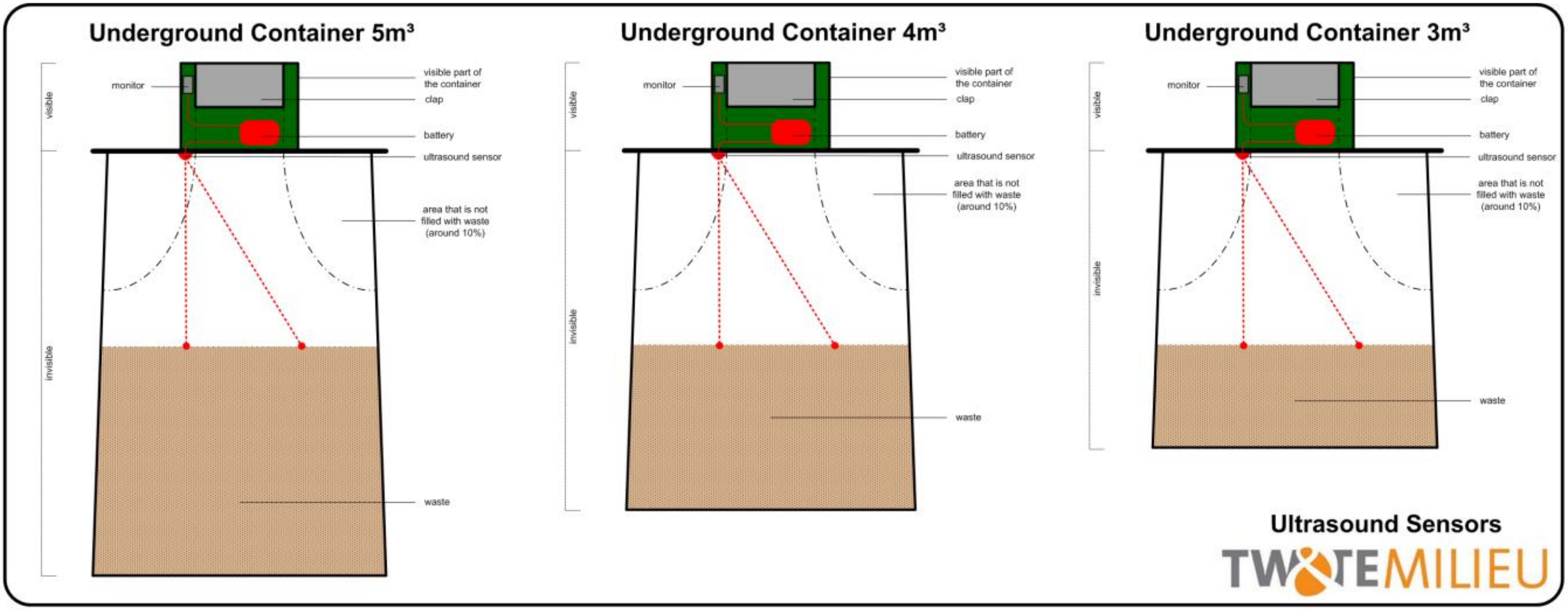


Appendix 16 – RFID applications in the containers

APPENDIX 17 – LEVEL SENSING WITH OPTICAL SENSORS

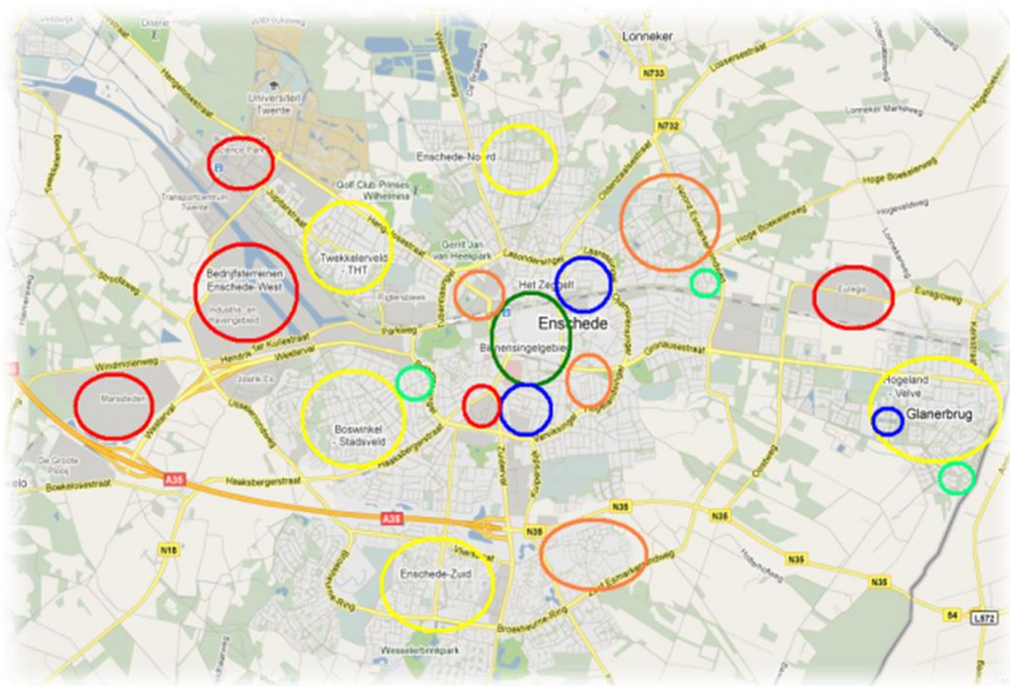


APPENDIX 18 – LEVEL SENSING WITH ULTRASONIC OR RADAR SENSORS



Measures NOT on scale

APPENDIX 19 – CATEGORIZATION POSSIBILITIES

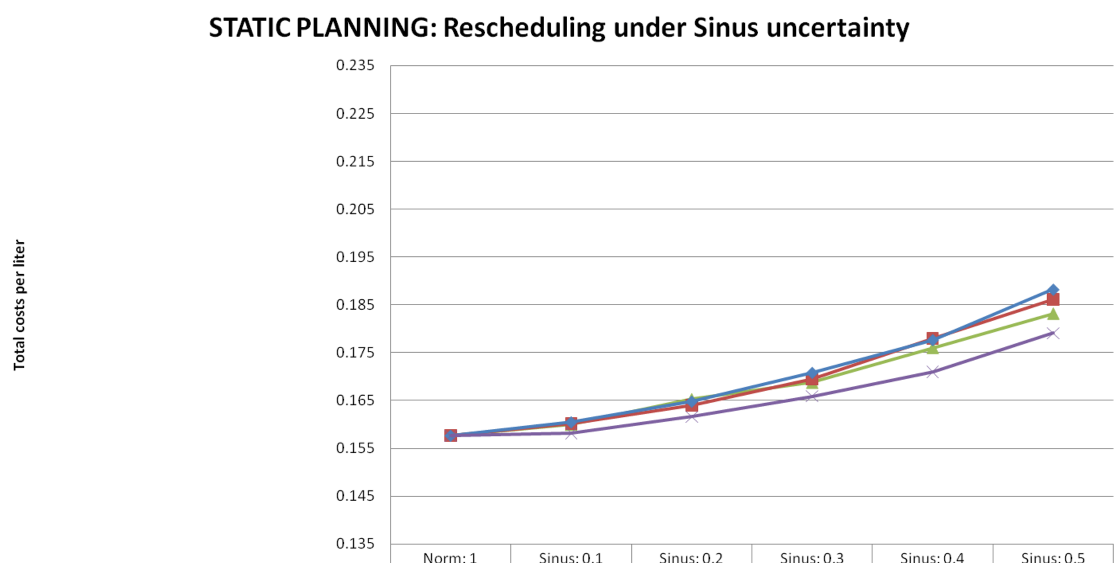


Testcontainer selection by Arnout Dam:						
Nr	**Municipality**	**ID**	**Location**	**Remarks**	**Size of cluster**	**DifTar in use**
1	Enschede	REN0464001	Van Loenshof	City center	2	NO
2	Enschede	REN0464002	Van Loenshof	City center	2	NO
3	Enschede	REN0300001	Hengelosestraat	Sub-urban area	3	NO
4	Enschede	REN0300002	Hengelosestraat	Sub-urban area	3	NO
5	Enschede	REN0300003	Hengelosestraat	Sub-urban area	3	NO
6	Enschede	REN0234001	Dr A H J Coppestraat	Retirement home	1	NO
7	Enschede	REN0309001	Madioenstraat 2	City center (close to restaurant)	2	NO
8	Enschede	REN0309002	Madioenstraat 2	City center (close to restaurant)	2	NO
9	Enschede	REN0233001	IJsselstraat	Appartment building	1	NO
10	Hengelo	RHE0345001	Willemstraat	City center (many stores)	3	YES
11	Hengelo	RHE0345002	Willemstraat	City center (many stores)	3	YES
12	Hengelo	RHE0345003	Willemstraat	City center (many stores)	3	YES
13	Hengelo	RHE0148001	Oldenzaalsestraat	Sub-urban area	1	YES
14	Hengelo	RHE0156001	Christiaan Huygenslaan	Sub-urban area	2	YES
15	Hengelo	RHE0156002	Christiaan Huygenslaan	Sub-urban area	2	YES
16	Almelo	RAL0225001	Aletta Jacobsstraat	City center	2	NO
17	Almelo	RAL0225002	Aletta Jacobsstraat	City center	2	NO
18	Oldenzaal	ROL1025001	Molenstraat	Sub-urban area	2	NO
19	Oldenzaal	ROL1025002	Molenstraat	Sub-urban area	2	NO
20	Hof van Twen-te	RHT5007001	Goor, Waterstraat	Rural area	1	NO

APPENDIX 20 – PHOTOVOLTAIC UNDERGROUND CONTAINER IN EINDHOVEN

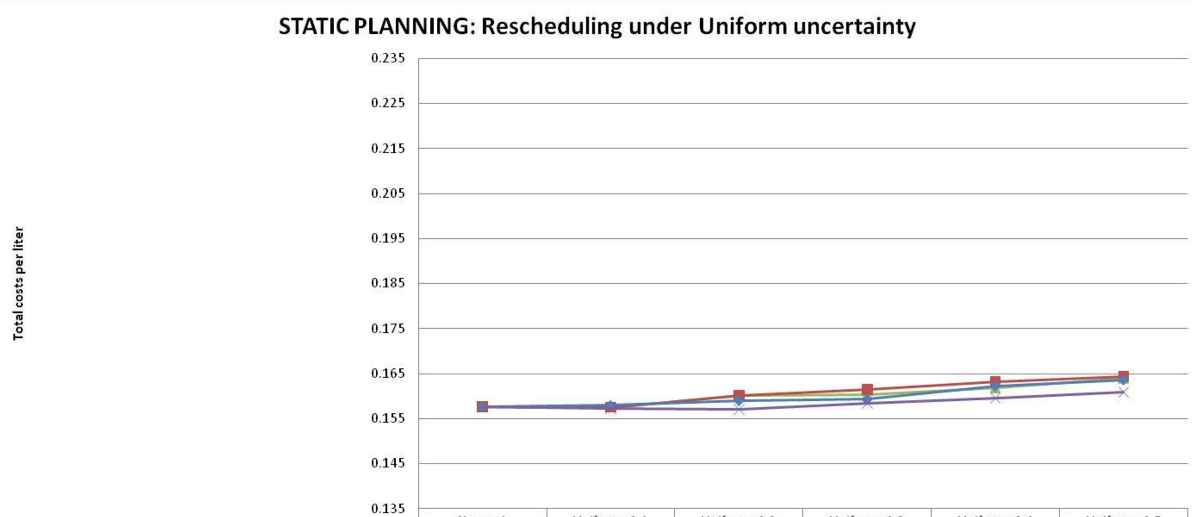
APPENDIX 21 – COMPUTATIONAL RESULTS: STATIC PLANNING

378 containers



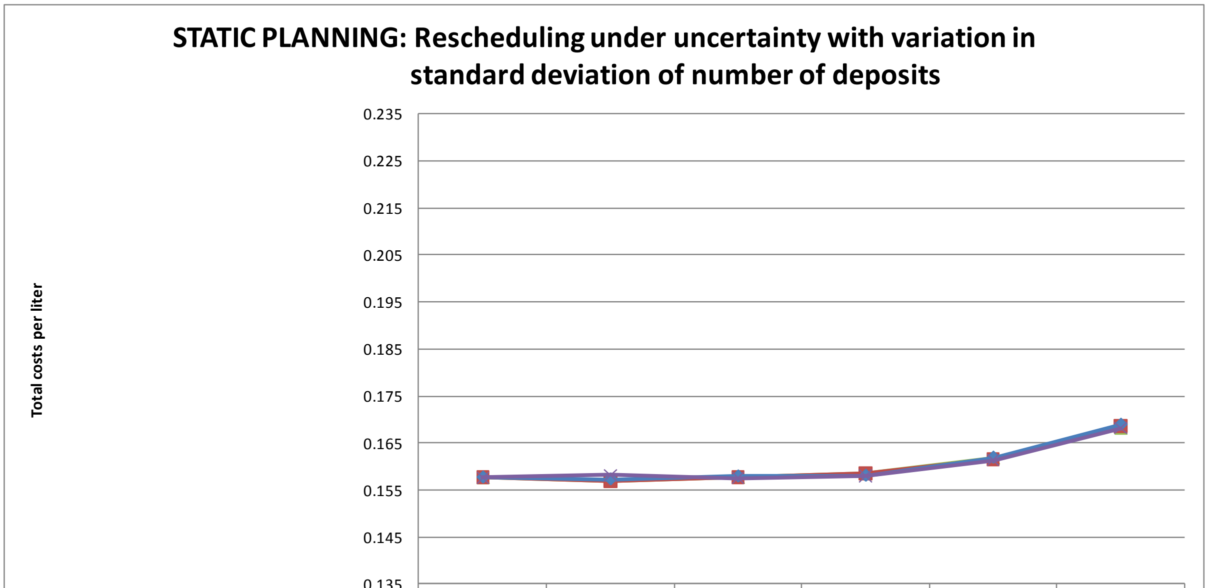
	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.158	0.160	0.165	0.169	0.176	0.183
Reschedule option 3, NO SENSORS (every truck after capacity problem)	0.158	0.160	0.164	0.169	0.178	0.186
Reschedule option 4, NO SENSORS (after Twence visit, single truck after capacity problem)	0.158	0.160	0.165	0.171	0.178	0.188
Reschedule option 2, SENSORS	0.158	0.158	0.162	0.166	0.171	0.179

Sinus variation of uncertainty (first row; 1=default / no effect)



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.158	0.158	0.160	0.160	0.162	0.164
Reschedule option 3, NO SENSORS (every truck after capacity problem)	0.158	0.158	0.160	0.161	0.163	0.164
Reschedule option 4, NO SENSORS (after Twence visit, single truck after capacity problem)	0.158	0.158	0.159	0.159	0.162	0.164
Reschedule option 2, SENSORS	0.158	0.157	0.157	0.158	0.159	0.161

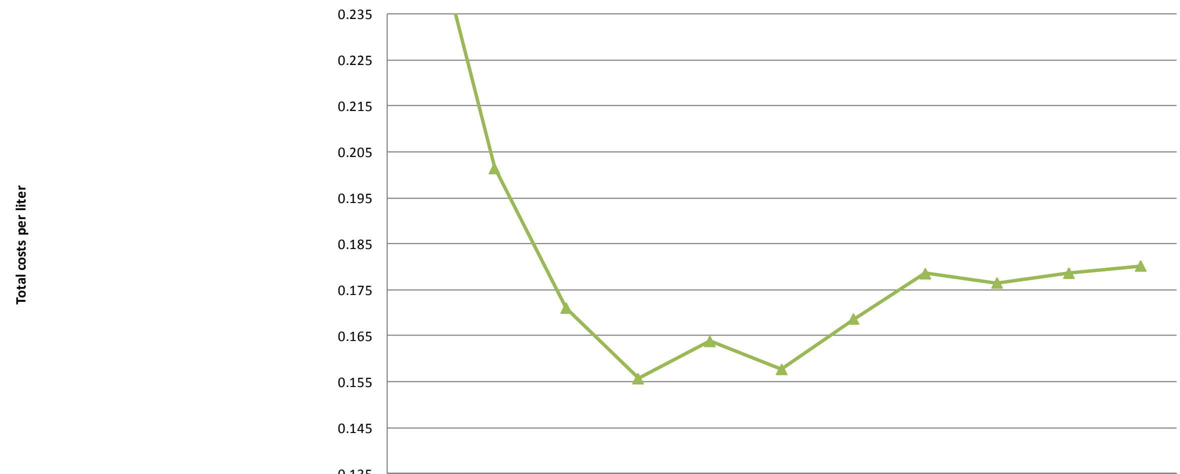
Uniform disposit variation of uncertainty (first row; 1=default / no effect)



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.158	0.157	0.158	0.159	0.162	0.168
Reschedule option 3, NO SENSORS (every truck after capacity problem)	0.158	0.157	0.158	0.159	0.161	0.169
Reschedule option 4, NO SENSORS (after Twence visit, single truck after capacity problem)	0.158	0.157	0.158	0.158	0.162	0.169
Reschedule option 2, SENSORS	0.158	0.158	0.158	0.158	0.161	0.168

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

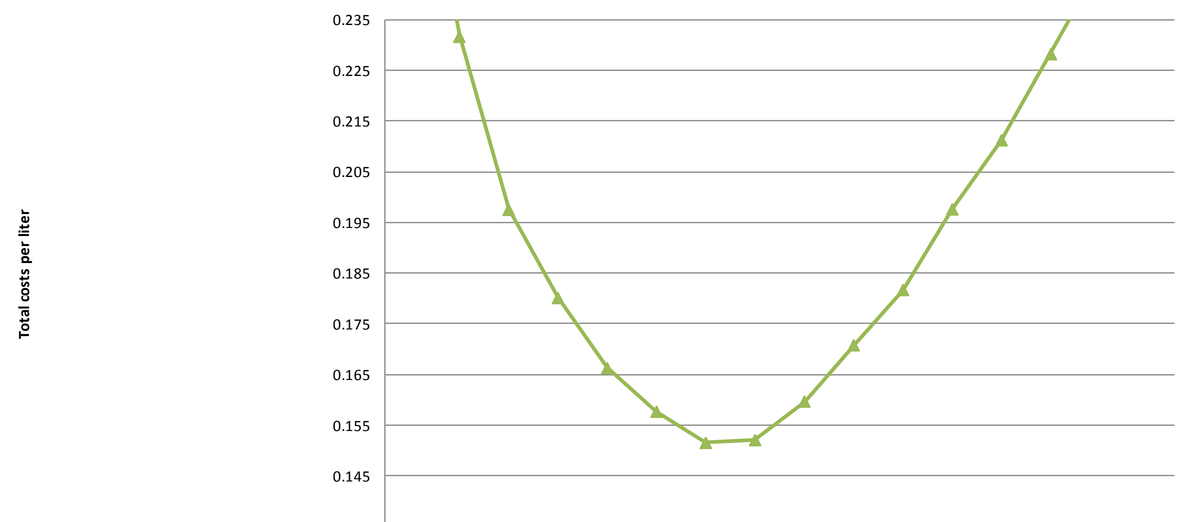
STATIC PLANNING: Experiments with the maximum number of containers that are emptied during one workday



	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.263	0.202	0.171	0.156	0.164	0.158	0.169	0.179	0.177	0.179	0.180

Static Max represents the ratio of containers that are emptied during one workday against the total number of containers in use (Static Max = 1 is the default scenario with a 22% emptyings frequency per day of all active containers Twente Milieu has at the

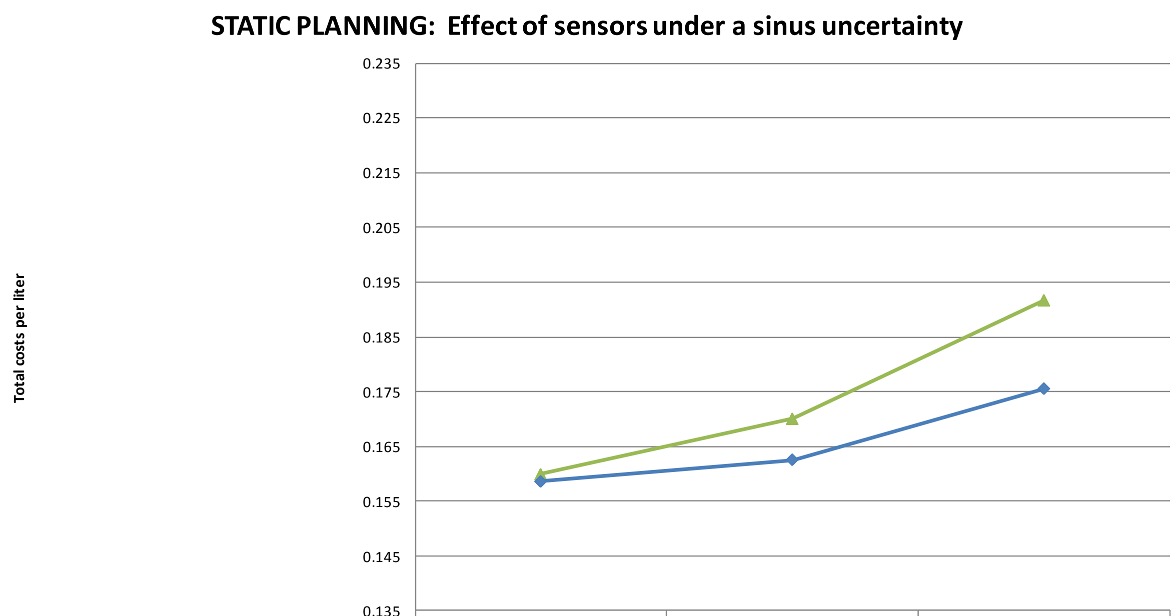
STATIC PLANNING: Experiments with a variation in the mean of the EXPECTED number of disposits



	Mean: 0.5	Mean: 0.6	Mean: 0.7	Mean: 0.8	Mean: 0.9	Mean: 1	Mean: 1.1	Mean: 1.2	Mean: 1.3	Mean: 1.4	Mean: 1.5	Mean: 1.6	Mean: 1.7	Mean: 1.8	Mean: 1.9	Mean: 2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.283	0.232	0.198	0.180	0.166	0.158	0.151	0.152	0.160	0.171	0.182	0.198	0.211	0.228	0.246	0.264

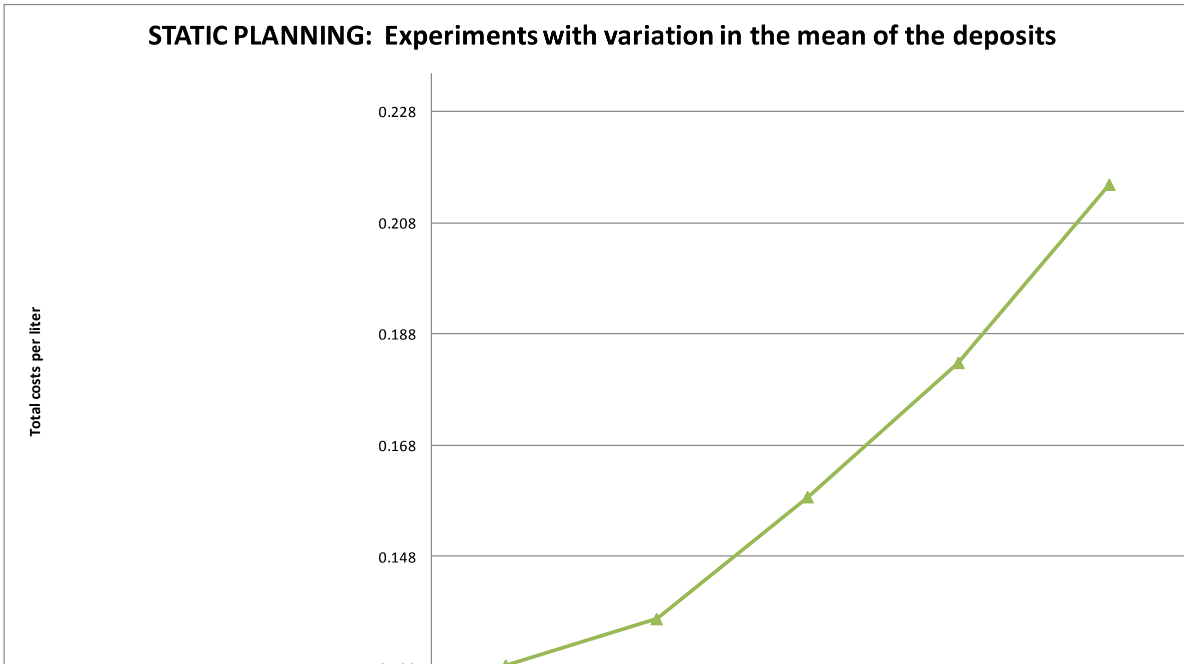
Mean stands for the average of expected disposits of an individual container.
The default mean is given by a gamma distribution (alpha: 1.93, beta: 5.88) that equals 11.35.
This mean than is multiplied by the mean factors given in the first row

700 containers



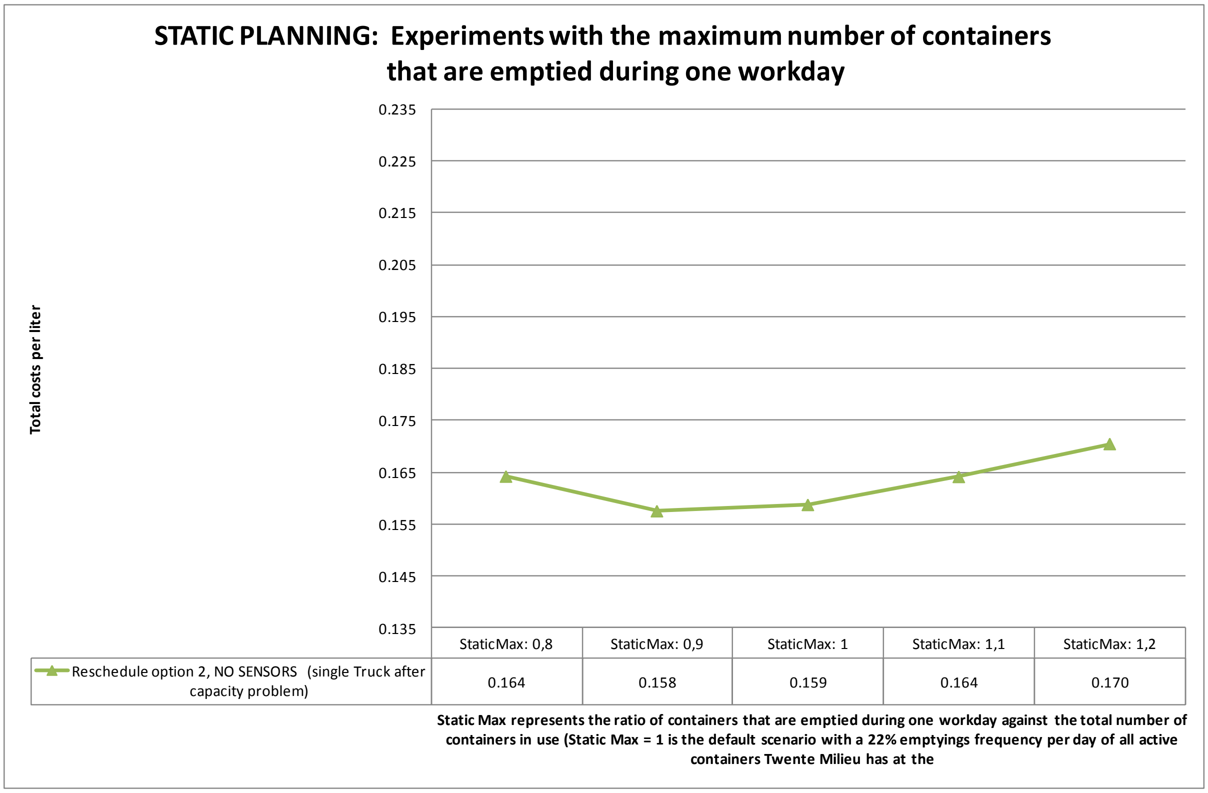
	Norm: 1	Sinus: 0,2	Sinus: 0,4
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.160	0.170	0.192
Reschedule option 2, SENSORS (single Truck after capacity problem)	0.159	0.163	0.175

Sinus variation



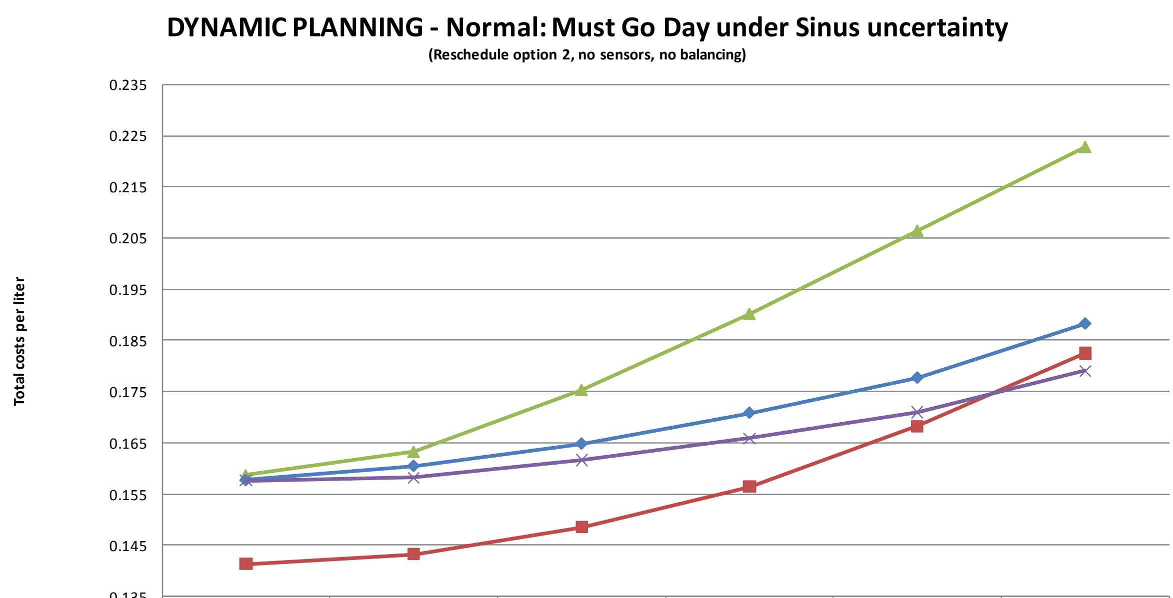
	Mean: 0,8	Mean: 0,9	Mean: 1	Mean: 1,1	Mean: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.128	0.137	0.159	0.183	0.215

Mean variation


STATIC PLANNING: Experiments with the maximum number of containers that are emptied during one workday
Total costs per liter
0.235
0.225
0.215
0.205
0.195
0.185
0.175
0.165
0.155
0.145
0.135
StaticMax: 0,8
StaticMax: 0,9
StaticMax: 1
StaticMax: 1,1
StaticMax: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.164
0.158
0.159
0.164
0.170
Static Max represents the ratio of containers that are emptied during one workday against the total number of containers in use (Static Max = 1 is the default scenario with a 22% emptyings frequency per day of all active containers Twente Milieu has at the

APPENDIX 22
– COMPUTATIONAL RESULTS DYNAMIC PLANNING – NORMAL

378 containers

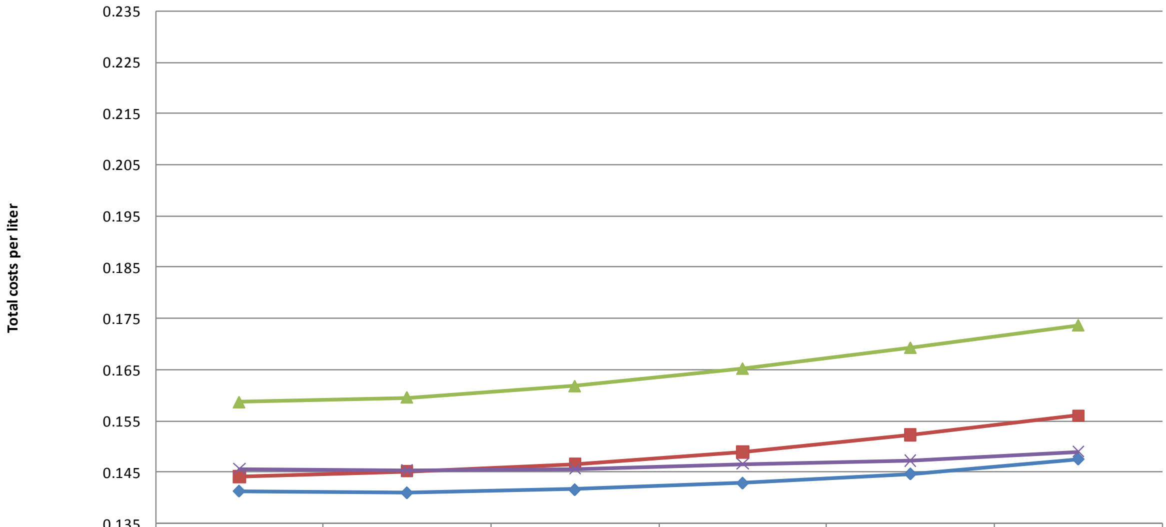


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 0	0.159	0.163	0.175	0.190	0.206	0.223
Must Go Day: 1	0.141	0.143	0.149	0.156	0.168	0.182
Must Go Day: 2	0.158	0.160	0.165	0.171	0.178	0.188
Must Go Day: 3	0.158	0.158	0.162	0.166	0.171	0.179

Sinus variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - Normal: Must Go Day under Uniform uncertainty

(Reschedule option 2, no sensors, no balancing)

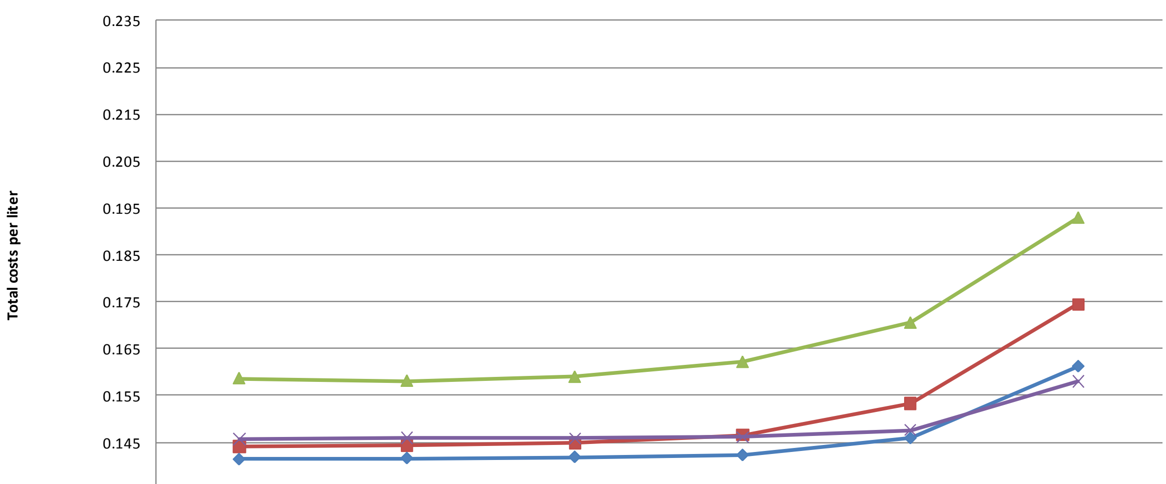


	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 0	0.159	0.160	0.162	0.165	0.169	0.174
Must Go Day: 1	0.144	0.145	0.147	0.149	0.152	0.156
Must Go Day: 2	0.141	0.141	0.142	0.143	0.145	0.147
Must Go Day: 3	0.146	0.145	0.146	0.147	0.147	0.149

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - Normal: Must Go Day under uncertainty with variation in standard deviation of number of deposits

(Reschedule option 2, no sensors, no balancing)

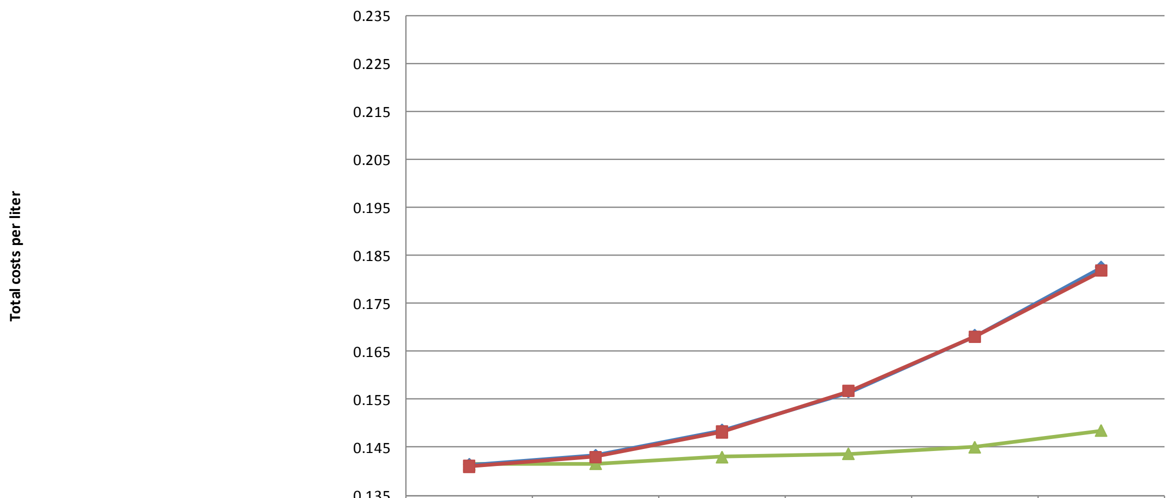


	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 0	0.159	0.158	0.159	0.162	0.170	0.193
Must Go Day: 1	0.144	0.144	0.145	0.147	0.153	0.174
Must Go Day: 2	0.141	0.142	0.142	0.142	0.146	0.161
Must Go Day: 3	0.146	0.146	0.146	0.146	0.148	0.158

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

DYNAMIC PLANNING - Normal: Effect of Sensors with a sinus uncertainty

(no balancing)

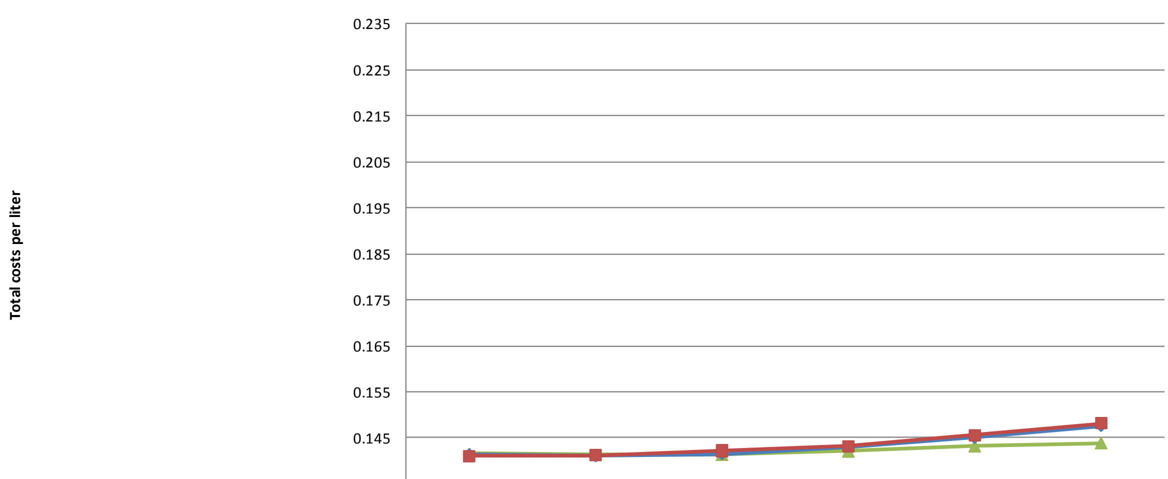


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Reschedule option 2, SENSORS (single truck after capacity problem)	0.142	0.142	0.143	0.144	0.145	0.148
Reschedule option 3, NO SENSORS (single truck after capacity problem and after a Twence visit)	0.141	0.143	0.149	0.156	0.168	0.182
Reschedule 4, NO SENSORS (all the trucks, after a single capacity problem and after a Twence visit)	0.141	0.143	0.148	0.157	0.168	0.182

Sinus variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - Normal: Effect of Sensors with an uniform uncertainty

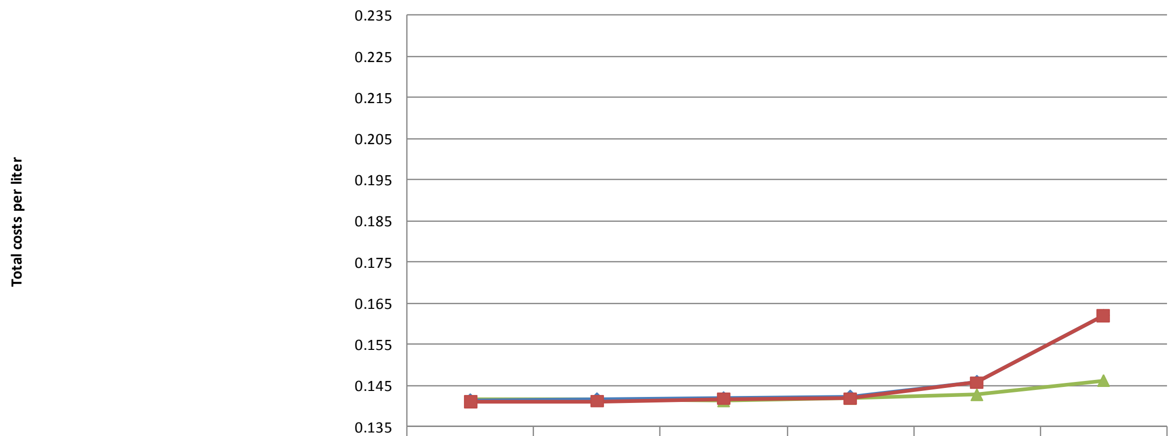
(no balancing)



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Reschedule option 2, SENSORS (single truck after capacity problem)	0.142	0.141	0.141	0.142	0.143	0.144
Reschedule option 3, NO SENSORS (single truck after capacity problem and after a Twence visit)	0.141	0.141	0.141	0.143	0.145	0.148
Reschedule 4, NO SENSORS (all the trucks, after a single capacity problem and after a Twence visit)	0.141	0.141	0.142	0.143	0.146	0.148

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

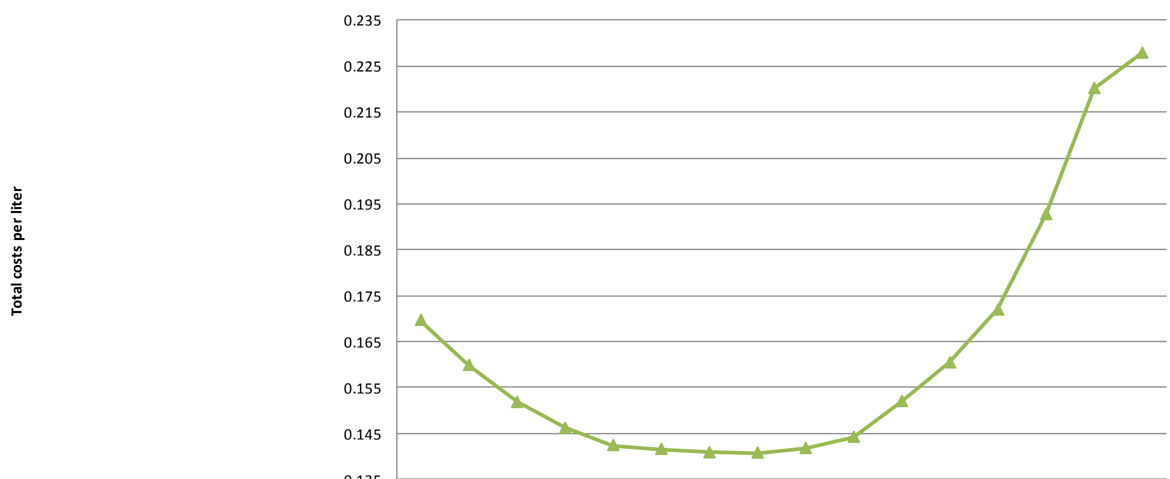
DYNAMIC PLANNING - Normal: Effect of Sensors with a uncertainty in standard deviation of number of deposits (no balancing)



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Reschedule option 2, SENSORS (single truck after capacity problem)	0.142	0.141	0.141	0.142	0.143	0.146
Reschedule option 3, NO SENSORS (single truck after capacity problem and after a Twence visit)	0.141	0.142	0.142	0.142	0.146	0.162
Reschedule 4, NO SENSORS (all the trucks, after a single capacity problem and after a Twence visit)	0.141	0.141	0.142	0.142	0.146	0.162

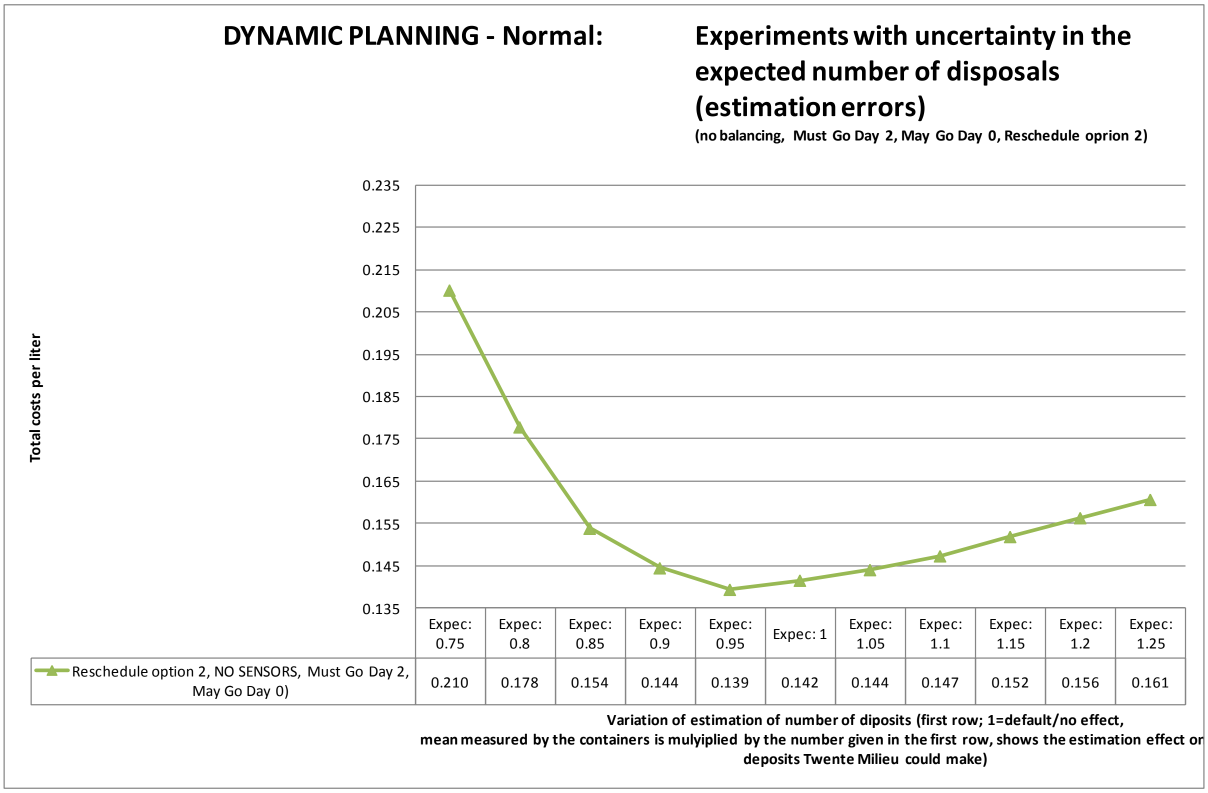
Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

DYNAMIC PLANNING - Normal: Experiments with uncertainty in the mean of the number of disposals
(no balancing, Must Go Day 2, May Go Day 0, Reschedule oprion 2)



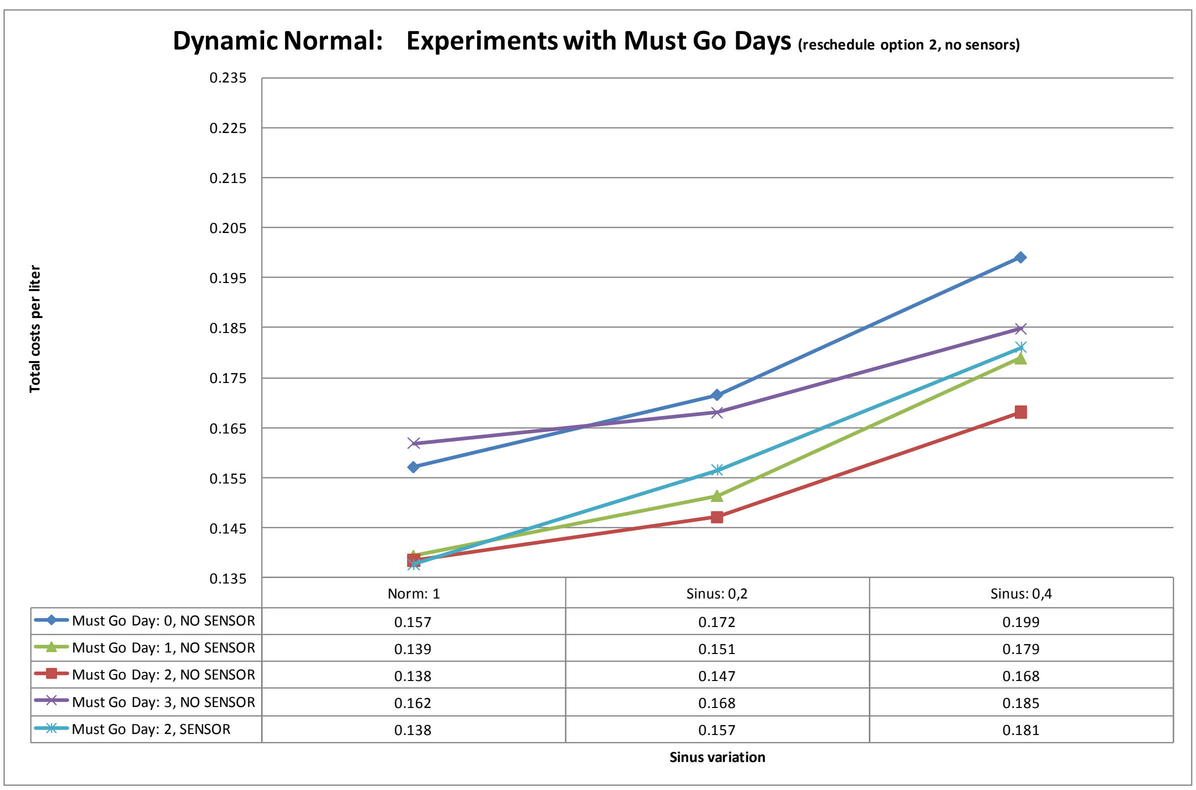
	Mean :0.5	Mean :0.6	Mean :0.7	Mean :0.8	Mean :0.9	Mean :1	Mean :1.1	Mean :1.2	Mean :1.3	Mean :1.4	Mean :1.5	Mean :1.6	Mean :1.7	Mean :1.8	Mean :1.9	Mean :2
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.170	0.160	0.152	0.146	0.142	0.142	0.141	0.141	0.142	0.144	0.152	0.160	0.172	0.193	0.220	0.228

Mean stands for the average of expected disposits of an individual container.
The default mean is given by a gamma distribution (alpha: 1.93, beta: 5.88) that equals 11.35.
This mean than is multiplied by the mean factors given in the first row (first row

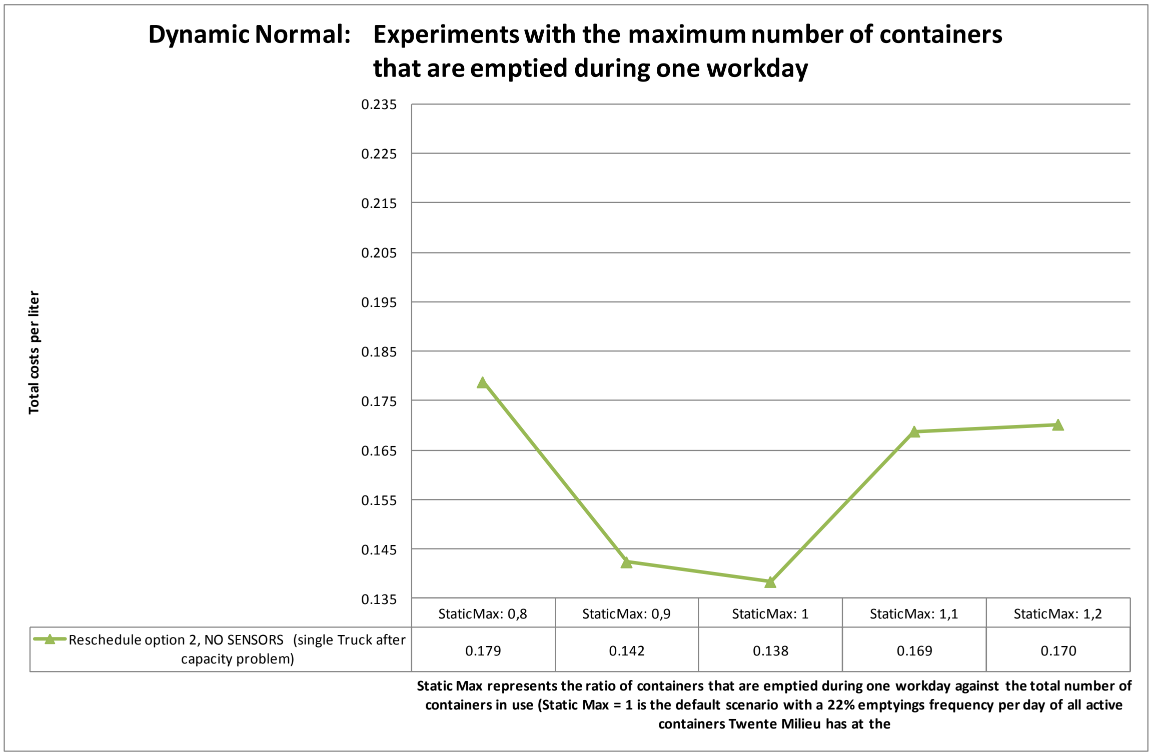


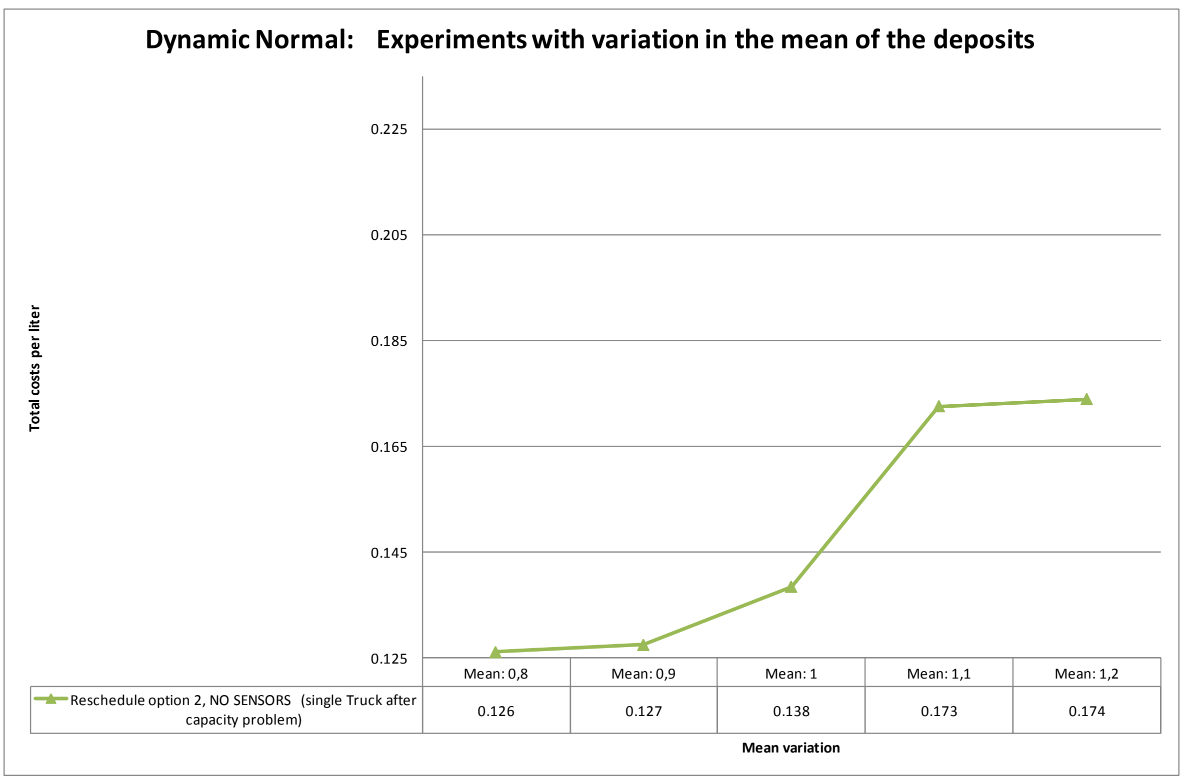
	Expec: 0.75	Expec: 0.8	Expec: 0.85	Expec: 0.9	Expec: 0.95	Expec: 1	Expec: 1.05	Expec: 1.1	Expec: 1.15	Expec: 1.2	Expec: 1.25
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.210	0.178	0.154	0.144	0.139	0.142	0.144	0.147	0.152	0.156	0.161

700 containers



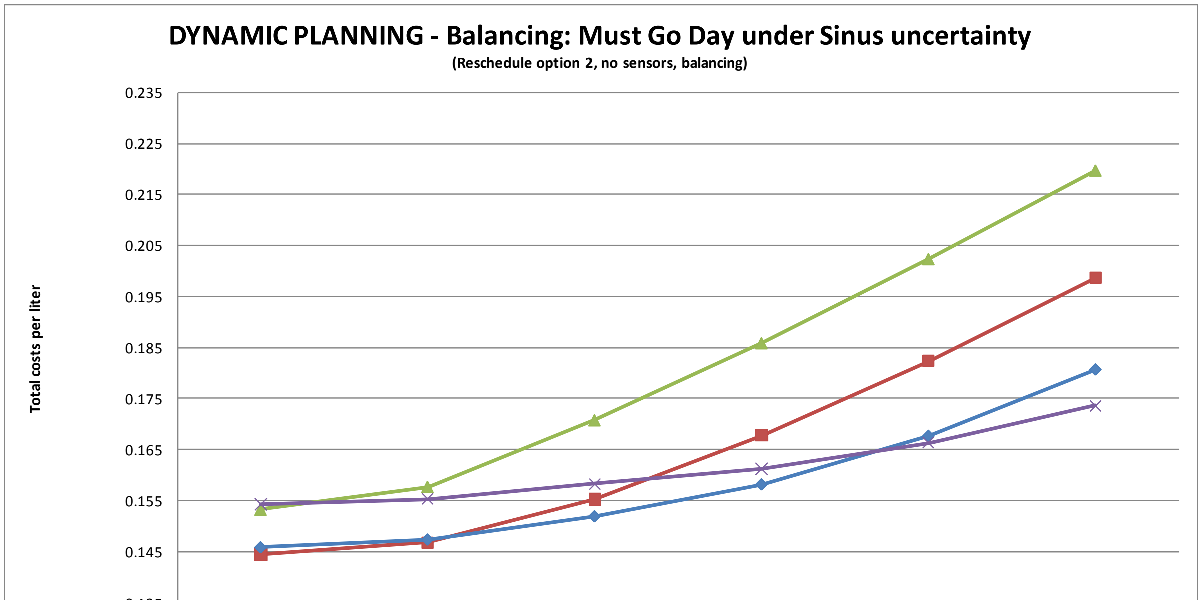
	Norm: 1	Sinus: 0,2	Sinus: 0,4
Must Go Day: 0, NO SENSOR	0.157	0.172	0.199
Must Go Day: 1, NO SENSOR	0.139	0.151	0.179
Must Go Day: 2, NO SENSOR	0.138	0.147	0.168
Must Go Day: 3, NO SENSOR	0.162	0.168	0.185
Must Go Day: 2, SENSOR	0.138	0.157	0.181


Dynamic Normal: Experiments with the maximum number of containers that are emptied during one workday
Total costs per liter
0.235
0.225
0.215
0.205
0.195
0.185
0.175
0.165
0.155
0.145
0.135
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
StaticMax: 0,8
StaticMax: 0,9
StaticMax: 1
StaticMax: 1,1
StaticMax: 1,2
0.179
0.142
0.138
0.169
0.170
Static Max represents the ratio of containers that are emptied during one workday against the total number of containers in use (Static Max = 1 is the default scenario with a 22% emptyings frequency per day of all active containers Twente Milieu has at the


Dynamic Normal: Experiments with variation in the mean of the deposits
Total costs per liter
0.225
0.205
0.185
0.165
0.145
0.125
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
Mean: 0,8
Mean: 0,9
Mean: 1
Mean: 1,1
Mean: 1,2
0.126
0.127
0.138
0.173
0.174
Mean variation

Appendix 23
– Computational results Dynamic Planning with Balancing

378 containers

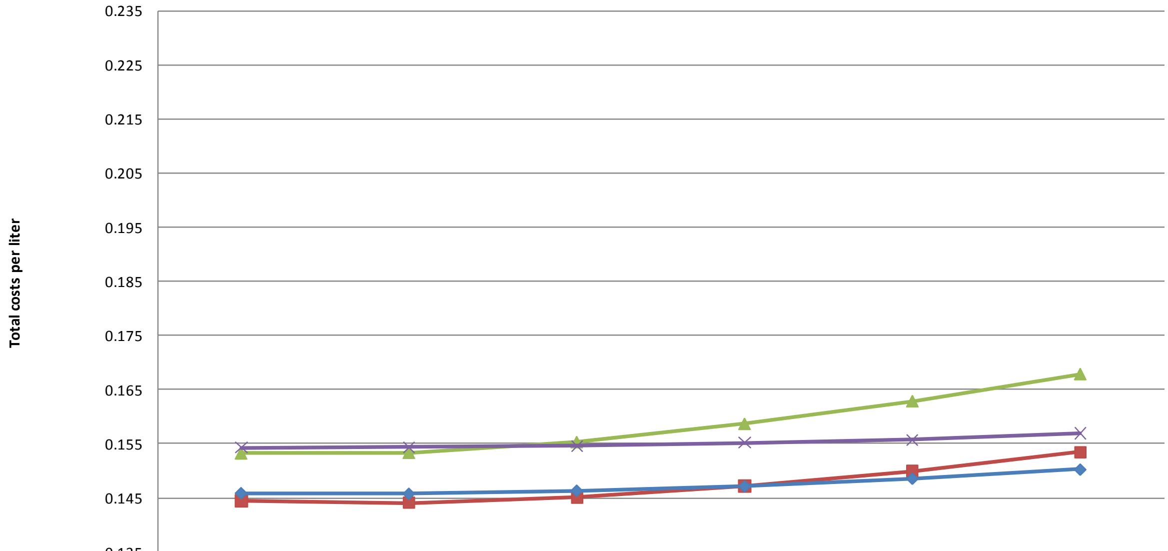


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 0	0.153	0.158	0.171	0.186	0.202	0.220
Must Go Day: 1	0.144	0.147	0.155	0.168	0.182	0.199
Must Go Day: 2	0.146	0.147	0.152	0.158	0.168	0.181
Must Go Day: 3	0.154	0.155	0.158	0.161	0.166	0.174

Sinus variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - Balancing: Must Go Day under Uniform uncertainty

(Reschedule option 2, no sensors, balancing)

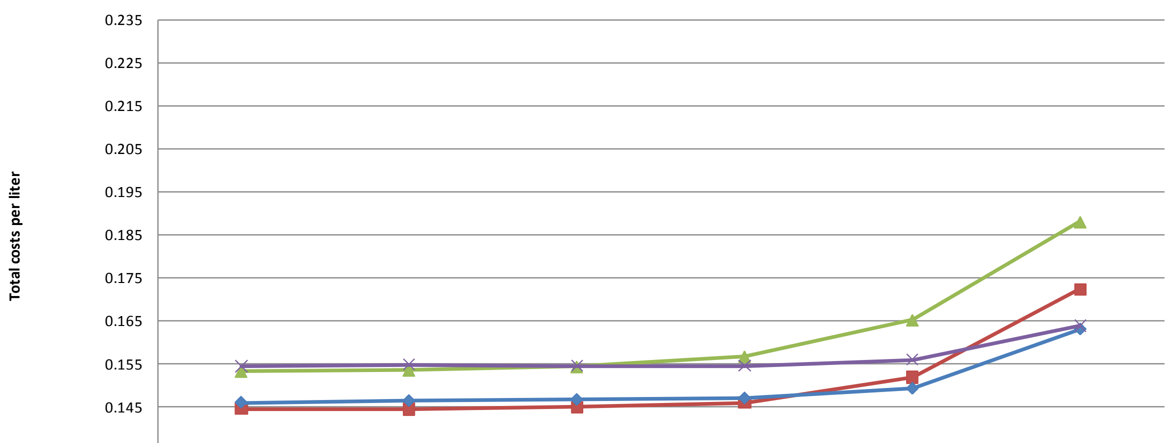


	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 0	0.153	0.153	0.155	0.159	0.163	0.168
Must Go Day: 1	0.144	0.144	0.145	0.147	0.150	0.153
Must Go Day: 2	0.146	0.146	0.146	0.147	0.149	0.150
Must Go Day: 3	0.154	0.154	0.155	0.155	0.156	0.157

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - Balancing: Must Go Day under uncertainty with variation in standard deviation of number of diposits

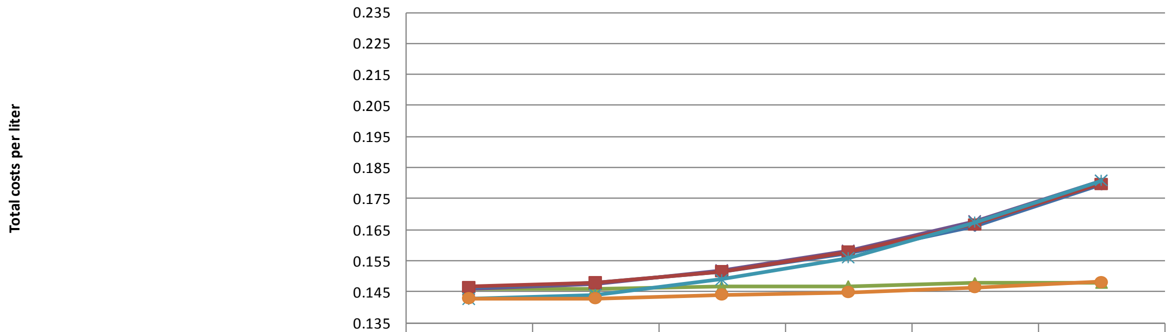
(Reschedule option 2, no sensors, balancing)



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 0	0.153	0.153	0.154	0.157	0.165	0.188
Must Go Day: 1	0.144	0.144	0.145	0.146	0.152	0.172
Must Go Day: 2	0.146	0.146	0.147	0.147	0.149	0.163
Must Go Day: 3	0.154	0.155	0.154	0.154	0.156	0.164

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

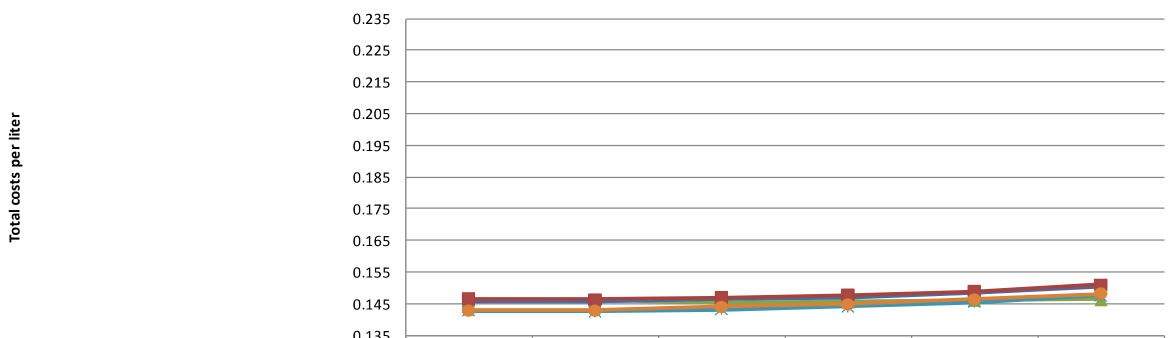
DYNAMIC PLANNING - Balancing: Effect of Sensors and several rescheduling options & the MaxBalancing option with a sinus uncertainty



	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Reschedule option 2, SENSORS (single truck after capacity problem)	0.146	0.146	0.147	0.147	0.148	0.148
Reschedule option 2, No Sensors (default)	0.146	0.147	0.152	0.158	0.168	0.181
Reschedule option 3, NO SENSORS (single truck after capacity problem and after a Twence visit)	0.146	0.148	0.151	0.157	0.166	0.180
Reschedule 4, NO SENSORS (all the trucks, after a single capacity problem and after a Twence visit)	0.147	0.148	0.152	0.158	0.167	0.180
Reschedule option 2, No Sensors, MaxBalancing on	0.143	0.144	0.149	0.156	0.167	0.181
Reschedule option 2, SENSORS, ="Reschedule option 2, No Sensors, MaxBalancing on	0.143	0.143	0.144	0.145	0.146	0.148

Sinus variation of uncertainty (first row; 1=default / no effect)

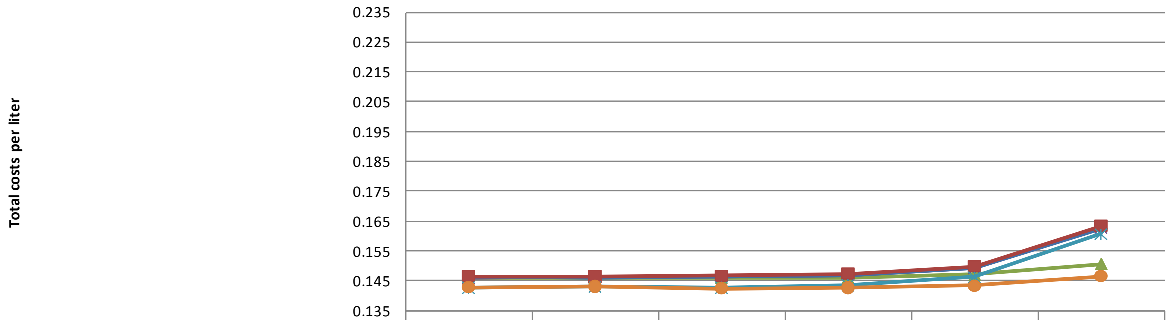
DYNAMIC PLANNING - Balancing: Effect of Sensors and several rescheduling options & the MaxBalancing option with an uniform uncertainty



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Reschedule option 2, SENSORS (single truck after capacity problem)	0.146	0.146	0.145	0.146	0.146	0.146
Reschedule option 2, No Sensors (default)	0.146	0.146	0.146	0.147	0.149	0.150
Reschedule option 3, NO SENSORS (single truck after capacity problem and after a Twence visit)	0.146	0.146	0.146	0.147	0.148	0.151
Reschedule 4, NO SENSORS (all the trucks, after a single capacity problem and after a Twence visit)	0.147	0.146	0.147	0.148	0.149	0.151
Reschedule option 2, No Sensors, MaxBalancing on	0.143	0.142	0.143	0.144	0.146	0.147
Reschedule option 2, SENSORS, ="Reschedule option 2, No Sensors, MaxBalancing on	0.143	0.143	0.144	0.145	0.146	0.148

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - Balancing: Effect of Sensors and several rescheduling options & the Max-Balancing option with an uncertainty in standard deviation

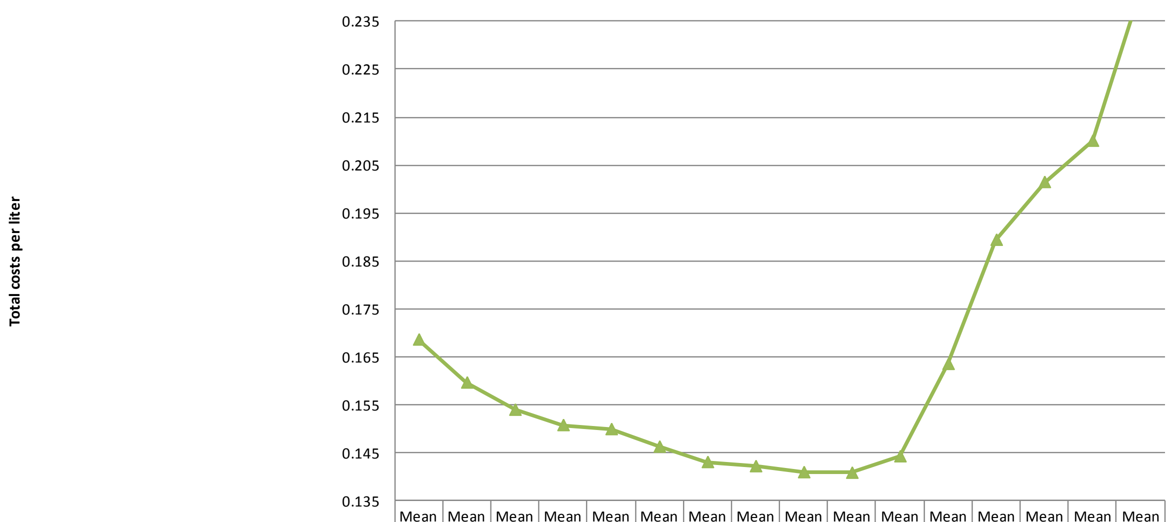


	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Reschedule option 2, SENSORS (single truck after capacity problem)	0.146	0.146	0.146	0.146	0.147	0.151
Reschedule option 2, No Sensors (default)	0.146	0.146	0.147	0.147	0.149	0.163
Reschedule option 3, NO SENSORS (single truck after capacity problem and after a Twence visit)	0.146	0.146	0.146	0.147	0.149	0.163
Reschedule 4, NO SENSORS (all the trucks, after a single capacity problem and after a Twence visit)	0.147	0.146	0.147	0.147	0.150	0.163
Reschedule option 2, No Sensors, MaxBalancing on	0.143	0.143	0.143	0.144	0.146	0.161
Reschedule option 2, SENSORS, ="Reschedule option 2, No Sensors, MaxBalancing on	0.143	0.143	0.142	0.143	0.143	0.147

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

DYNAMIC PLANNING - Balancing: Experiments with uncertainty in the mean of the number of disposals

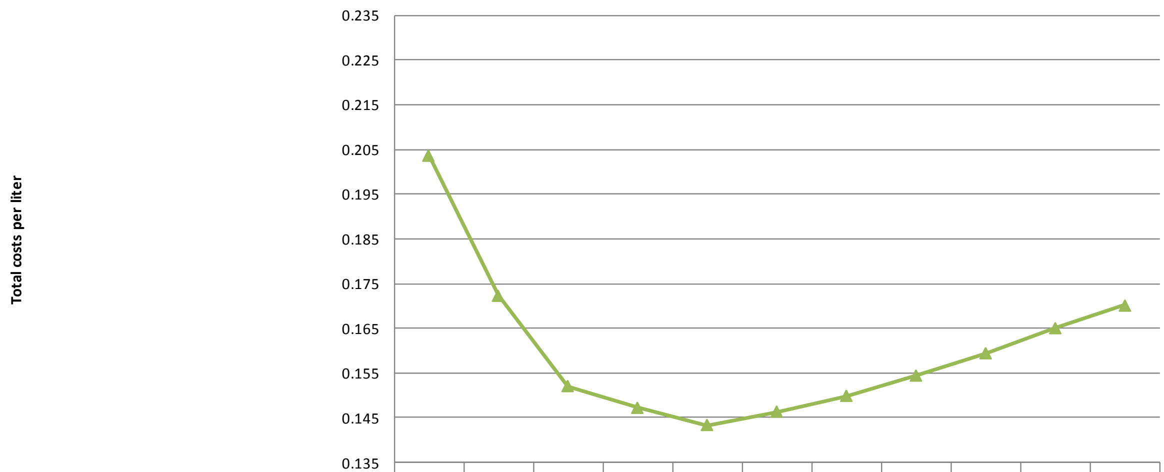
(balancing, Must Go Day 2, May Go Day 0, Reschedule oprion 2)



	Mean :0.5	Mean :0.6	Mean :0.7	Mean :0.8	Mean :0.9	Mean :1	Mean :1.1	Mean :1.2	Mean :1.3	Mean :1.4	Mean :1.5	Mean :1.6	Mean :1.7	Mean :1.8	Mean :1.9	Mean :2
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.169	0.160	0.154	0.151	0.150	0.146	0.143	0.142	0.141	0.141	0.144	0.163	0.189	0.201	0.210	0.242

Mean stands for the average of expected disposits of an individual container.
The default mean is given by a gamma distribution (alpha: 1.93, beta: 5.88) that equals 11.35.
This mean than is multiplied by the mean factors given in the first row (first row

DYNAMIC PLANNING - Balancing: Experiments with uncertainty in the expected number of disposals (estimation errors)
(no balancing, Must Go Day 2, May Go Day 0, Reschedule oprion 2)

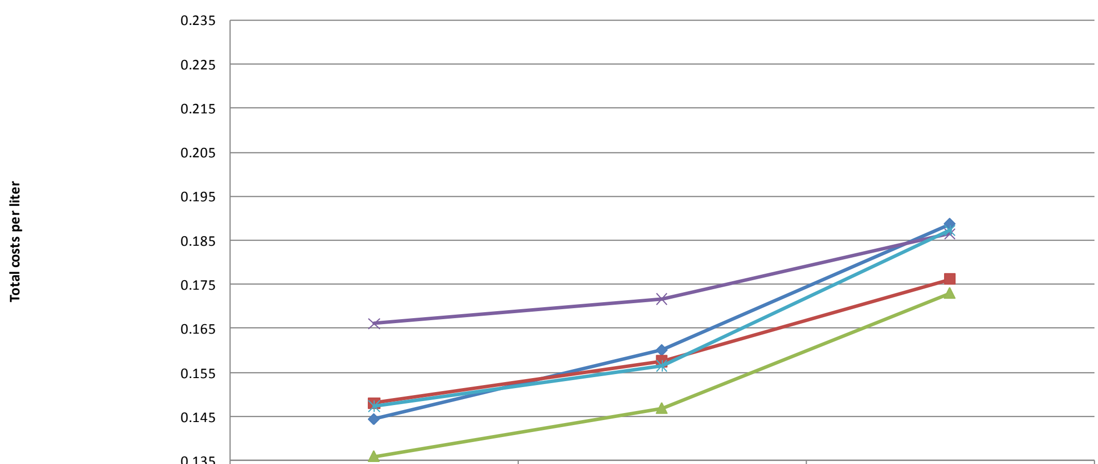


	Expec: 0.75	Expec: 0.8	Expec: 0.85	Expec: 0.9	Expec: 0.95	Expec: 1	Expec: 1.05	Expec: 1.1	Expec: 1.15	Expec: 1.2	Expec: 1.25
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.204	0.172	0.152	0.147	0.143	0.146	0.150	0.154	0.159	0.165	0.170

Variation of estimation of number of diposits (first row; 1=default/no effect, mean measured by the containers is mulyiplied by the number given in the first row, shows the estimation effect or deposits Twente Milieu could make)

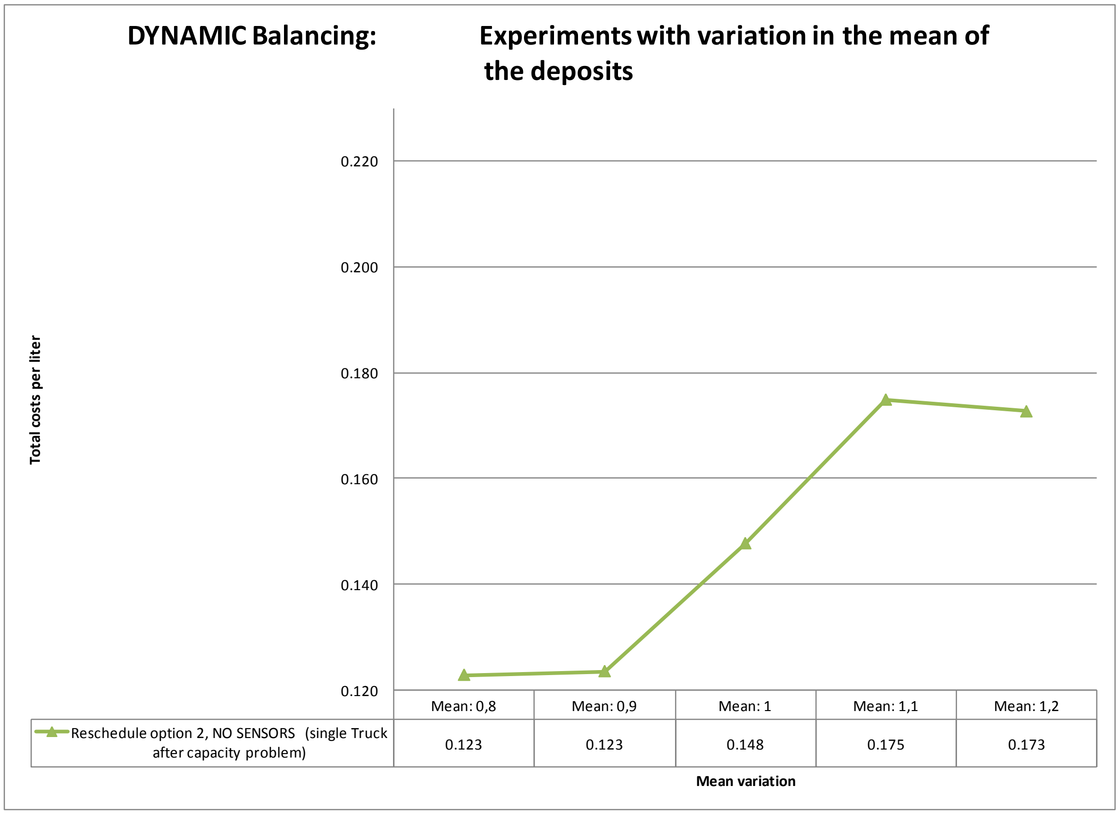
700 containers

Dynamic Balancing: Experiments with Must Go Days under a sinus uncertainty (reschedule option 2, no sensors)

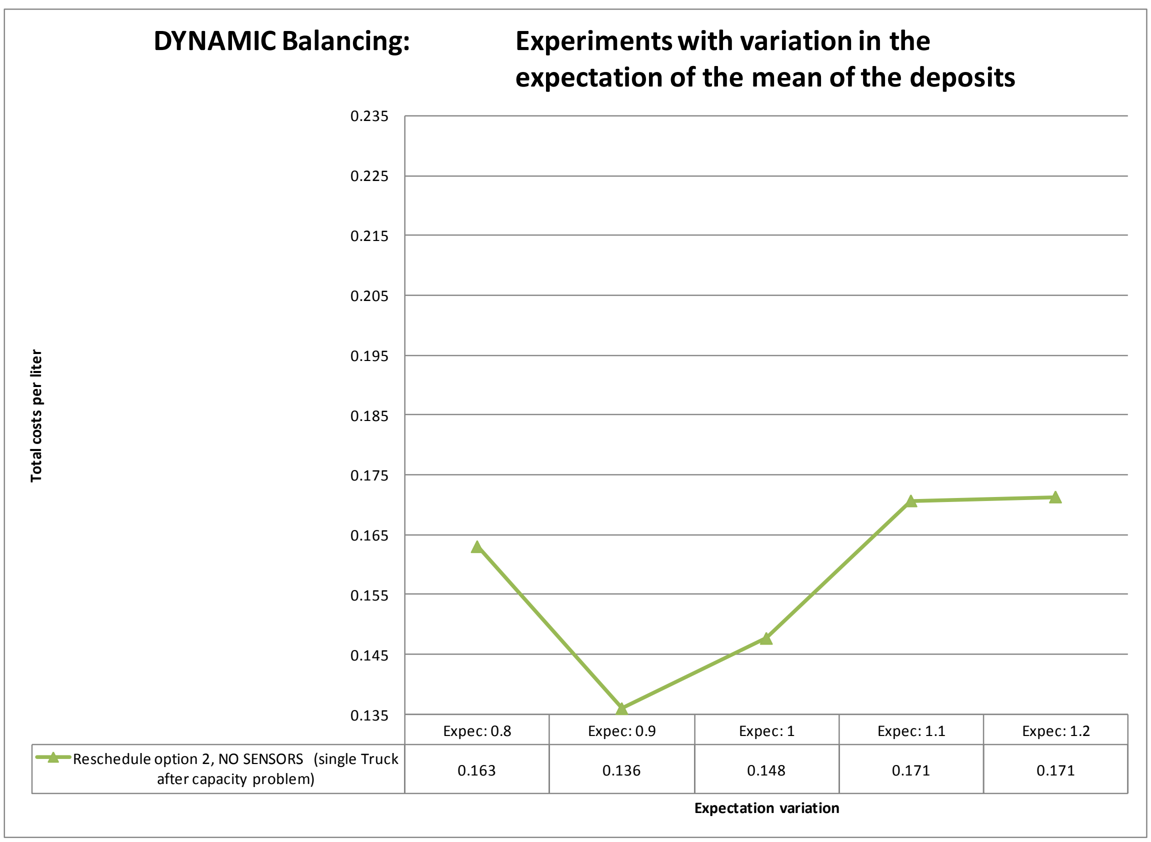


	Norm: 1	Sinus: 0,2	Sinus: 0,4
Must Go Day: 0, NO SENSOR	0.144	0.160	0.189
Must Go Day: 1, NO SENSOR	0.136	0.147	0.173
Must Go Day: 2, NO SENSOR	0.148	0.158	0.176
Must Go Day: 3, NO SENSOR	0.166	0.172	0.187
Must Go Day: 2, SENSOR	0.147	0.157	0.187

Sinus variation



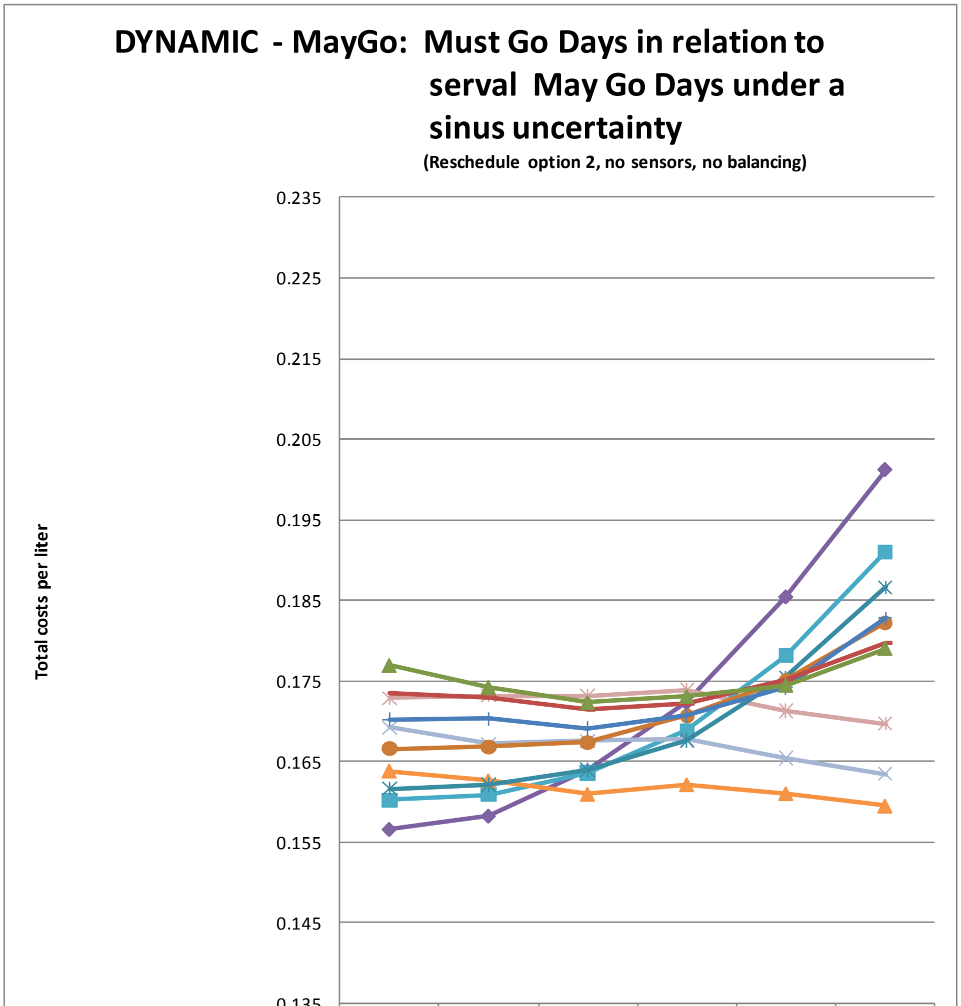
	Mean: 0,8	Mean: 0,9	Mean: 1	Mean: 1,1	Mean: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.123	0.123	0.148	0.175	0.173



	Expec: 0.8	Expec: 0.9	Expec: 1	Expec: 1.1	Expec: 1.2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.163	0.136	0.148	0.171	0.171

APPENDIX 24
– COMPUTATIONAL RESULTS DYNAMIC PLANNING WITH MAYGO-JOBS

378 containers

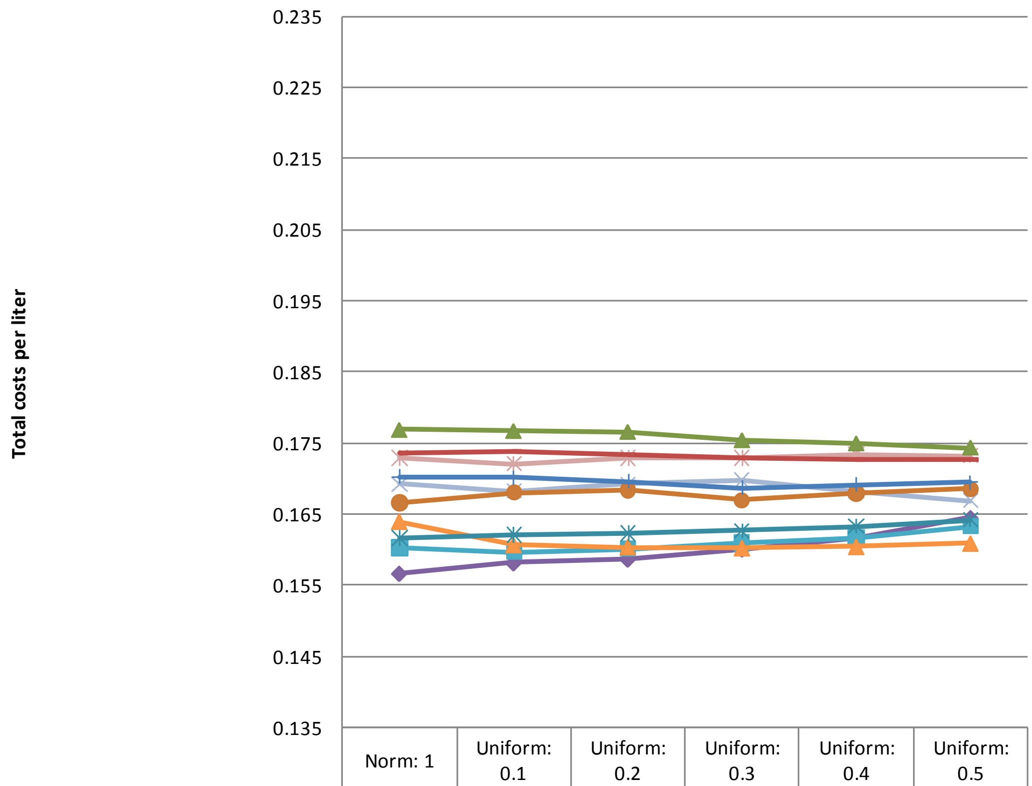


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 1	0.157	0.158	0.164	0.172	0.185	0.201
Must Go Day: 1, May Go Day: 2	0.160	0.161	0.164	0.169	0.178	0.191
Must Go Day: 1, May Go Day: 3	0.164	0.163	0.161	0.162	0.161	0.159
Must Go Day: 1, May Go Day: 4	0.169	0.167	0.168	0.168	0.165	0.163
Must Go Day: 1, May Go Day: 5	0.173	0.173	0.173	0.174	0.171	0.170
Must Go Day: 2, May Go Day: 1	0.162	0.162	0.164	0.168	0.175	0.187
Must Go Day: 2, May Go Day: 2	0.167	0.167	0.167	0.171	0.175	0.182
Must Go Day: 2, May Go Day: 3	0.170	0.170	0.169	0.171	0.174	0.183
Must Go Day: 2, May Go Day: 4	0.173	0.173	0.171	0.172	0.175	0.180
Must Go Day: 2, May Go Day: 5	0.177	0.174	0.172	0.173	0.174	0.179

Sinus variation of uncertainty (first row; 1=default / no effect)

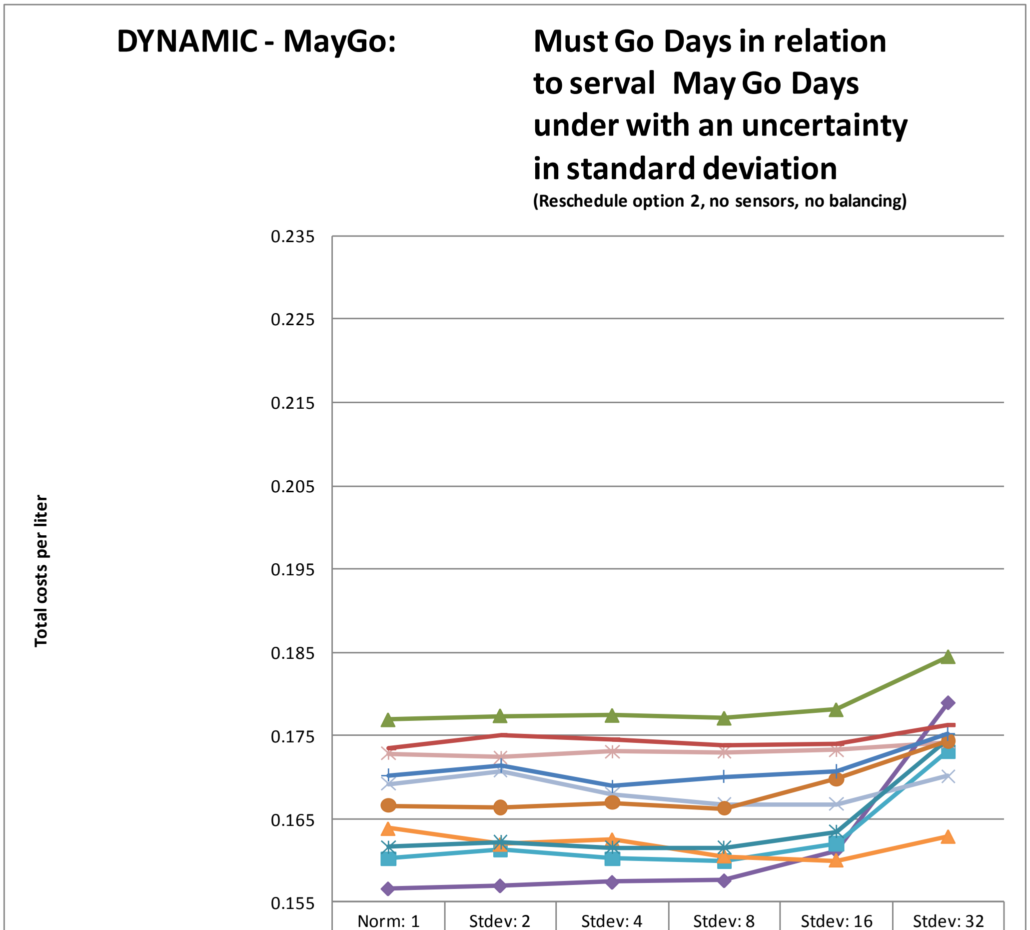
DYNAMIC - MayGo: Must Go Days in relation to serval May Go Days under an uniform uncertainty

(Reschedule option 2, no sensors, no balancing)



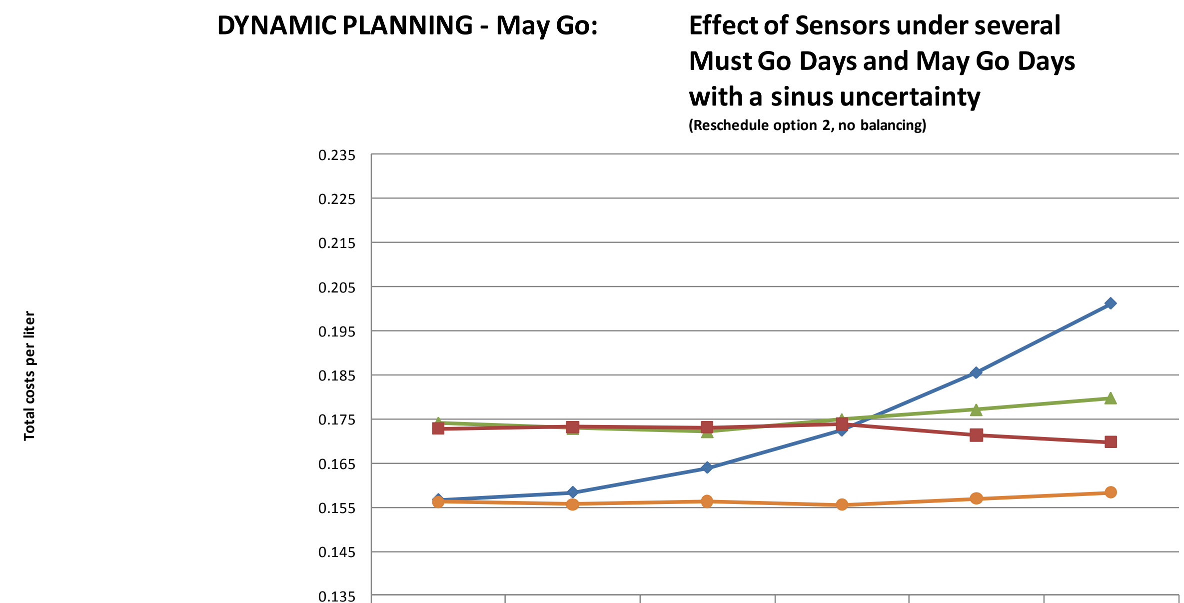
	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 1, May Go Day: 1	0.157	0.158	0.159	0.160	0.162	0.164
Must Go Day: 1, May Go Day: 2	0.160	0.160	0.160	0.161	0.162	0.163
Must Go Day: 1, May Go Day: 3	0.164	0.161	0.160	0.160	0.160	0.161
Must Go Day: 1, May Go Day: 4	0.169	0.168	0.169	0.170	0.168	0.167
Must Go Day: 1, May Go Day: 5	0.173	0.172	0.173	0.173	0.173	0.173
Must Go Day: 2, May Go Day: 1	0.162	0.162	0.162	0.163	0.163	0.164
Must Go Day: 2, May Go Day: 2	0.167	0.168	0.168	0.167	0.168	0.169
Must Go Day: 2, May Go Day: 3	0.170	0.170	0.170	0.169	0.169	0.169
Must Go Day: 2, May Go Day: 4	0.173	0.174	0.173	0.173	0.173	0.173
Must Go Day: 2, May Go Day: 5	0.177	0.177	0.177	0.175	0.175	0.174

Uniform deposit variation of uncertainty (first row; 1=default / no effect)



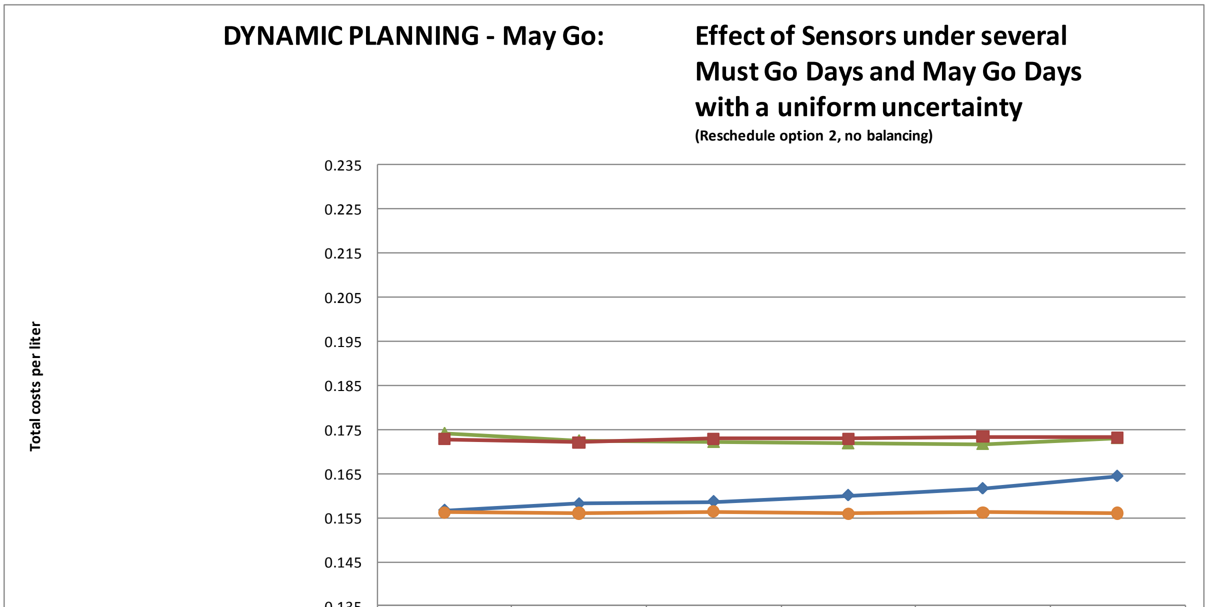
	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 1, May Go Day: 1	0.157	0.157	0.157	0.158	0.161	0.179
Must Go Day: 1, May Go Day: 2	0.160	0.161	0.160	0.160	0.162	0.173
Must Go Day: 1, May Go Day: 3	0.164	0.162	0.163	0.161	0.160	0.163
Must Go Day: 1, May Go Day: 4	0.169	0.171	0.168	0.167	0.167	0.170
Must Go Day: 1, May Go Day: 5	0.173	0.172	0.173	0.173	0.173	0.174
Must Go Day: 2, May Go Day: 1	0.162	0.162	0.162	0.162	0.163	0.174
Must Go Day: 2, May Go Day: 2	0.167	0.166	0.167	0.166	0.170	0.174
Must Go Day: 2, May Go Day: 3	0.170	0.171	0.169	0.170	0.171	0.175
Must Go Day: 2, May Go Day: 4	0.173	0.175	0.174	0.174	0.174	0.176
Must Go Day: 2, May Go Day: 5	0.177	0.177	0.177	0.177	0.178	0.184

Variation of standard deviation of number of deposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)



	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 1, NO SENSORS	0.157	0.158	0.164	0.172	0.185	0.201
Must Go Day: 1, May Go Day: 1, SENSORS	0.156	0.156	0.156	0.156	0.157	0.158
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.174	0.173	0.172	0.175	0.177	0.180
Must Go Day: 1, May Go Day: 5, SENSORS	0.173	0.173	0.173	0.174	0.171	0.170

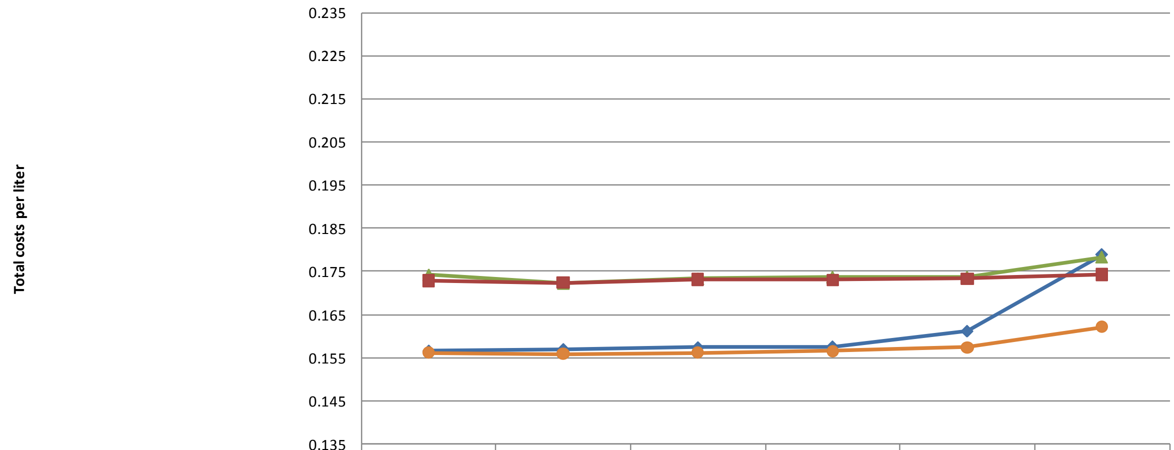
Sinus variation of uncertainty (first row; 1=default / no effect)



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 1, May Go Day: 1, NO SENSORS	0.157	0.158	0.159	0.160	0.162	0.164
Must Go Day: 1, May Go Day: 1, SENSORS	0.156	0.156	0.156	0.156	0.156	0.156
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.174	0.172	0.172	0.172	0.172	0.173
Must Go Day: 1, May Go Day: 5, SENSORS	0.173	0.172	0.173	0.173	0.173	0.173

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

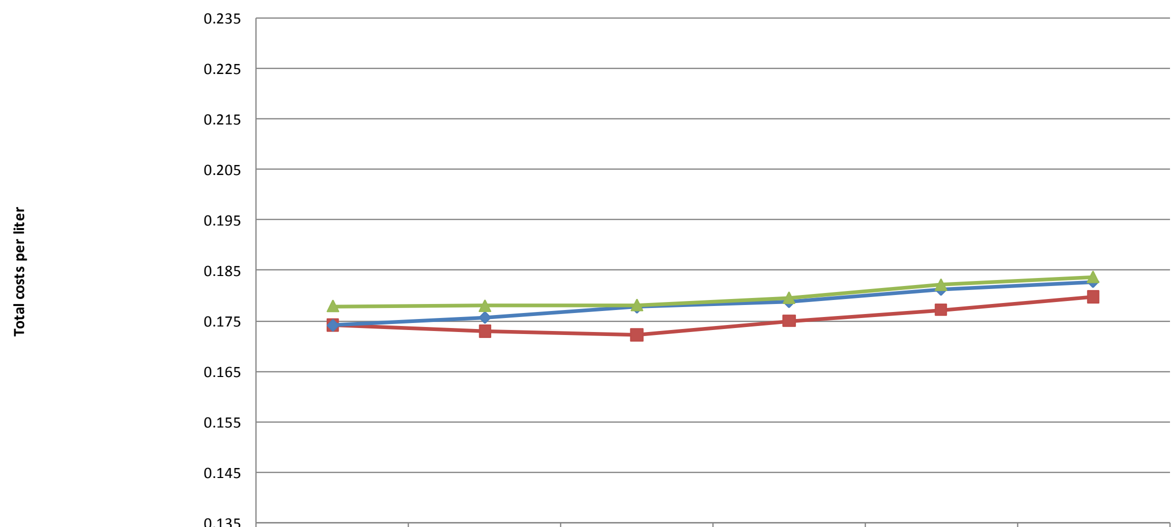
DYNAMIC PLANNING - May Go: Effect of Sensors under several Must Go Days and May Go Days with a uncertainty in standard deviation (Reschedule option 2, no balancing)



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 1, May Go Day: 1, NO SENSORS	0.157	0.157	0.157	0.158	0.161	0.179
Must Go Day: 1, May Go Day: 1, SENSORS	0.156	0.156	0.156	0.157	0.157	0.162
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.174	0.172	0.173	0.174	0.174	0.178
Must Go Day: 1, May Go Day: 5, SENSORS	0.173	0.172	0.173	0.173	0.173	0.174

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

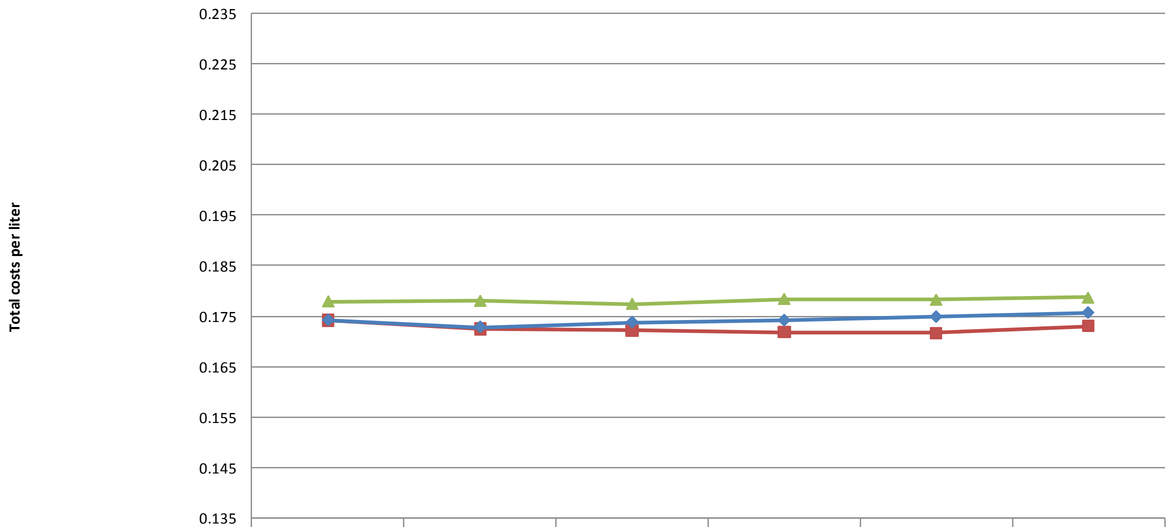
DYNAMIC PLANNING - May Go: Effect of several rescheduling options under a sinus uncertainty (Must Go Day: 1, May Go Day: 5, no balancing)



	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Reschedule option 2 (default)	0.174	0.173	0.172	0.175	0.177	0.180
Reschedule option 3	0.174	0.176	0.178	0.179	0.181	0.183
Reschedule option 4	0.178	0.178	0.178	0.180	0.182	0.184

Sinus variation of uncertainty (first row; 1=default / no effect)

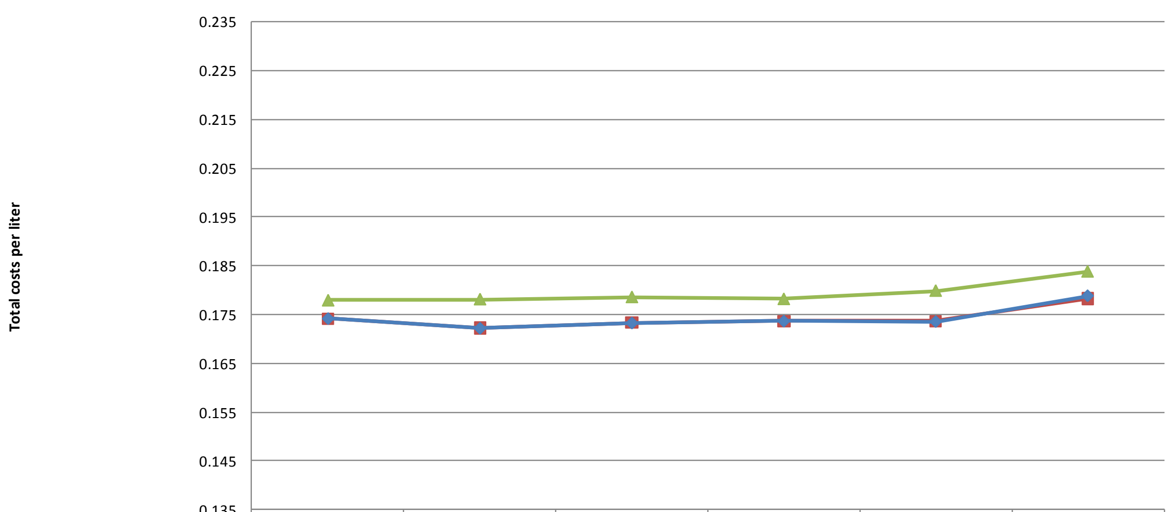
DYNAMIC PLANNING - May Go: **Effect of several rescheduling options under a uniform uncertainty**
(Must Go Day: 1, May Go Day: 5, no balancing)



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Reschedule option 2 (default)	0.174	0.172	0.172	0.172	0.172	0.173
Reschedule option 3	0.174	0.173	0.174	0.174	0.175	0.176
Reschedule option 4	0.178	0.178	0.177	0.178	0.178	0.179

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - May Go: **Effect of several rescheduling options under an uncertainty in standard deviation** (Must Go Day: 1, May Go Day: 5, no balancing)

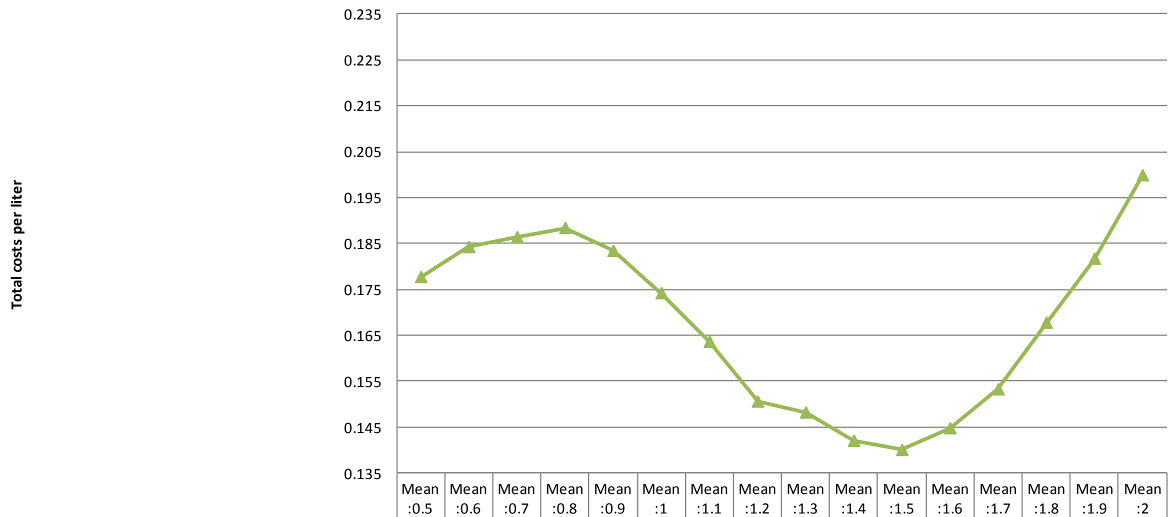


	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Reschedule option 2 (default)	0.174	0.172	0.173	0.174	0.174	0.178
Reschedule option 3	0.174	0.172	0.173	0.174	0.174	0.179
Reschedule option 4	0.178	0.178	0.179	0.178	0.180	0.184

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

DYNAMIC PLANNING - May Go: Experiments with uncertainty in the mean of the number of disposals

(no balancing, Must Go Day 1, May Go Day 5, Reschedule oprion 2)

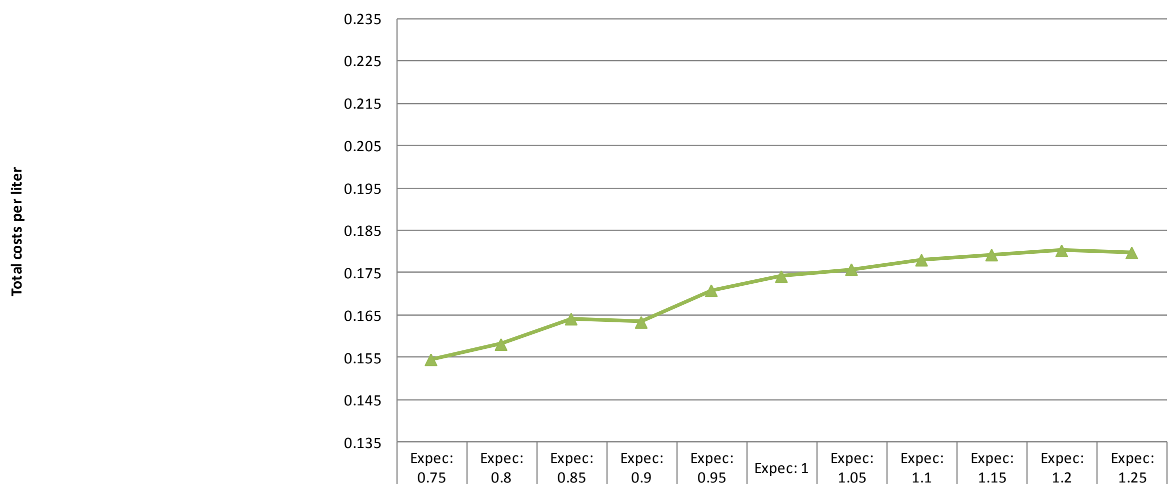


	Mean :0.5	Mean :0.6	Mean :0.7	Mean :0.8	Mean :0.9	Mean :1	Mean :1.1	Mean :1.2	Mean :1.3	Mean :1.4	Mean :1.5	Mean :1.6	Mean :1.7	Mean :1.8	Mean :1.9	Mean :2
Reschedule option 2, NO SENSORS, Must Go Day 1, May Go Day 5	0.178	0.184	0.186	0.188	0.183	0.174	0.164	0.151	0.148	0.142	0.140	0.145	0.153	0.168	0.182	0.200

Mean stands for the average of expected disposits of an individual container.
The default mean is given by a gamma distribution (alpha: 1.93, beta: 5.88) that equals 11.35.
This mean than is multiplied by the mean factors given in the first row (first row

DYNAMIC PLANNING - May Go: Experiments with uncertainty in the expected number of disposals (estimation errors)

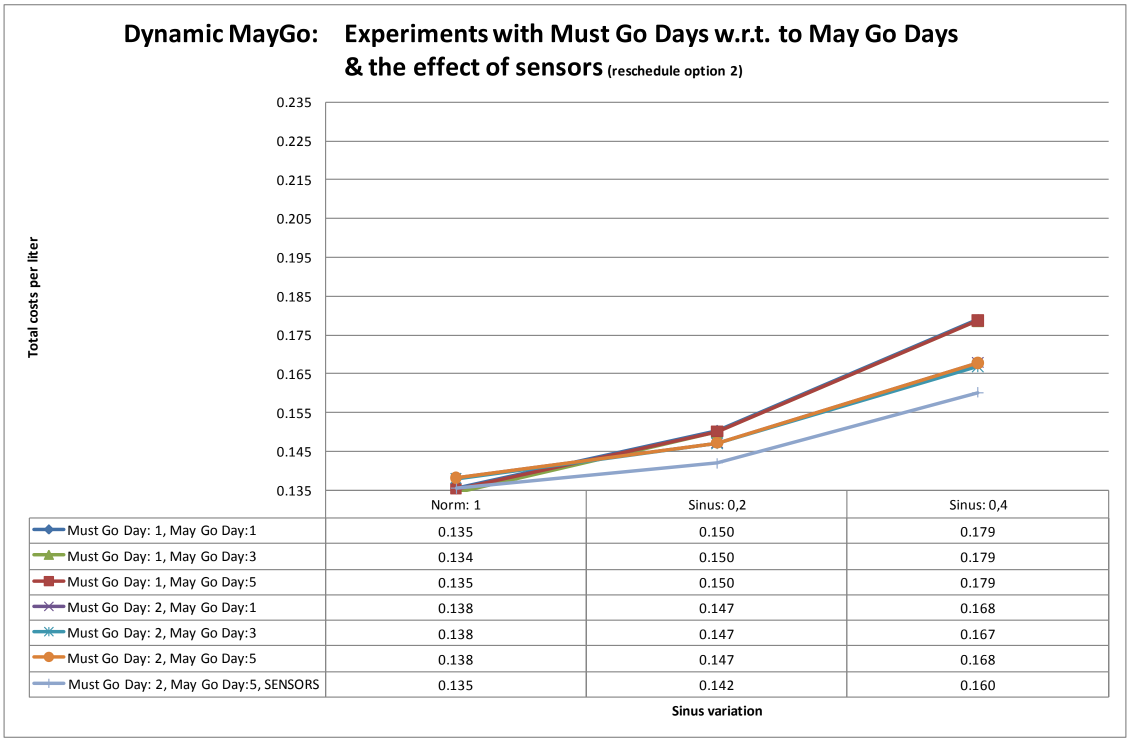
(no balancing, Must Go Day 1, May Go Day 5, Reschedule oprion 2)



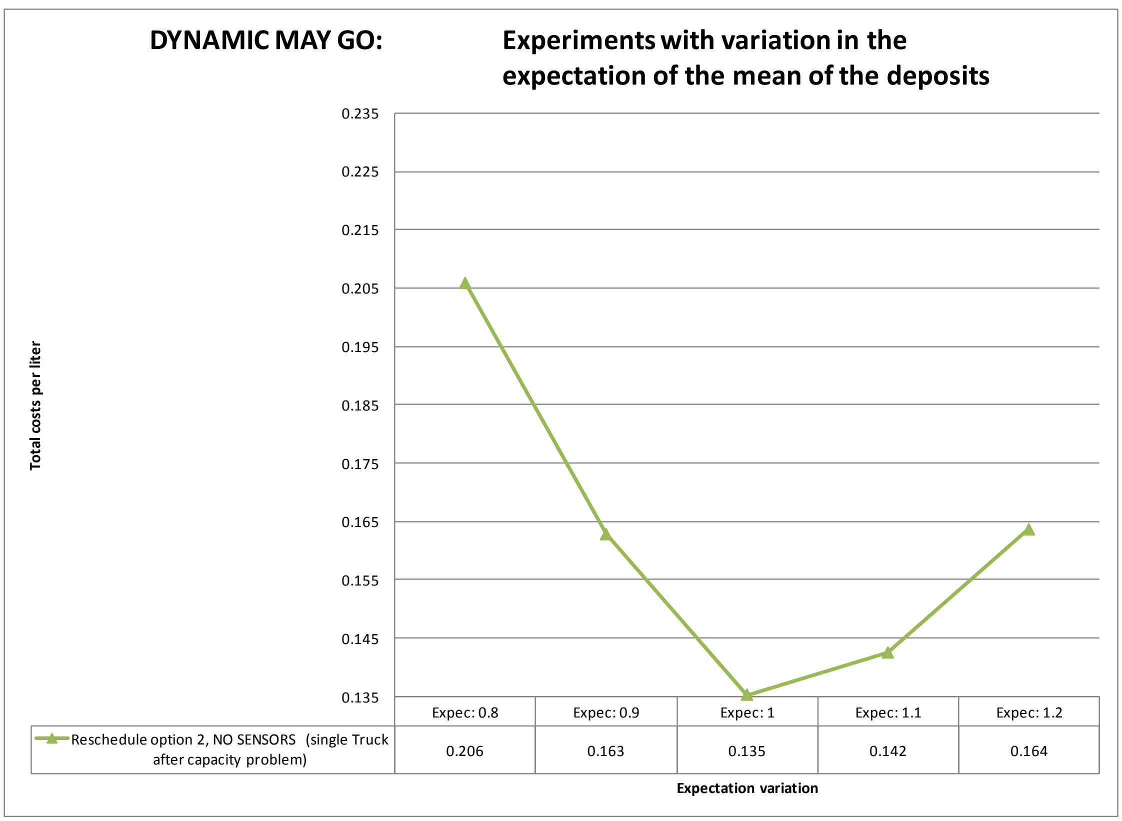
	Expec: 0.75	Expec: 0.8	Expec: 0.85	Expec: 0.9	Expec: 0.95	Expec: 1	Expec: 1.05	Expec: 1.1	Expec: 1.15	Expec: 1.2	Expec: 1.25
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.155	0.158	0.164	0.163	0.171	0.174	0.176	0.178	0.179	0.180	0.180

Variation of estimation of number of diposits (first row; 1=default/no effect,
mean measured by the containers is mulyiplied by the number given in the first row, shows the estimation effect or
deposits Twente Milieu could make)

700 containers



	Norm: 1	Sinus: 0,2	Sinus: 0,4
Must Go Day: 1, May Go Day:1	0.135	0.150	0.179
Must Go Day: 1, May Go Day:3	0.134	0.150	0.179
Must Go Day: 1, May Go Day:5	0.135	0.150	0.179
Must Go Day: 2, May Go Day:1	0.138	0.147	0.168
Must Go Day: 2, May Go Day:3	0.138	0.147	0.167
Must Go Day: 2, May Go Day:5	0.138	0.147	0.168
Must Go Day: 2, May Go Day:5, SENSORS	0.135	0.142	0.160



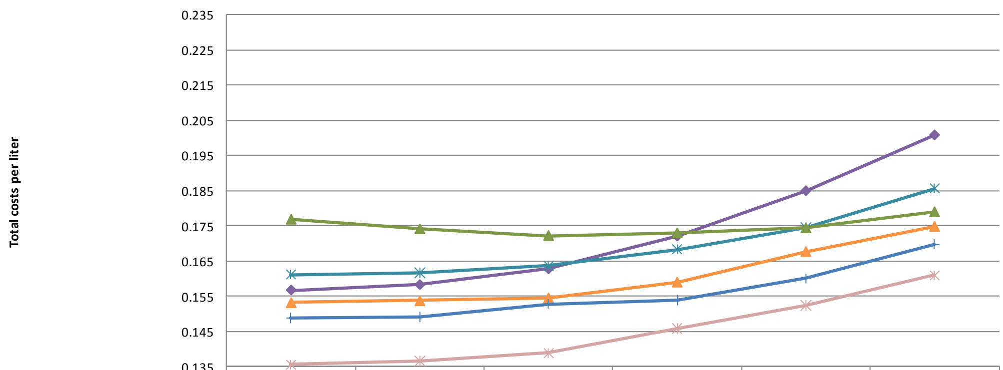
	Expec: 0.8	Expec: 0.9	Expec: 1	Expec: 1.1	Expec: 1.2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.206	0.163	0.135	0.142	0.164

Appendix 25
– Computational results Dynamic Planning with fixed amount of Must- and MayGo-jobs

378 containers

DYNAMIC PLANNING - MayGoFixed: Must Go Days in relation to serval May Go Days under a sinus uncertainty

(Reschedule option 2, no sensors, no balancing)

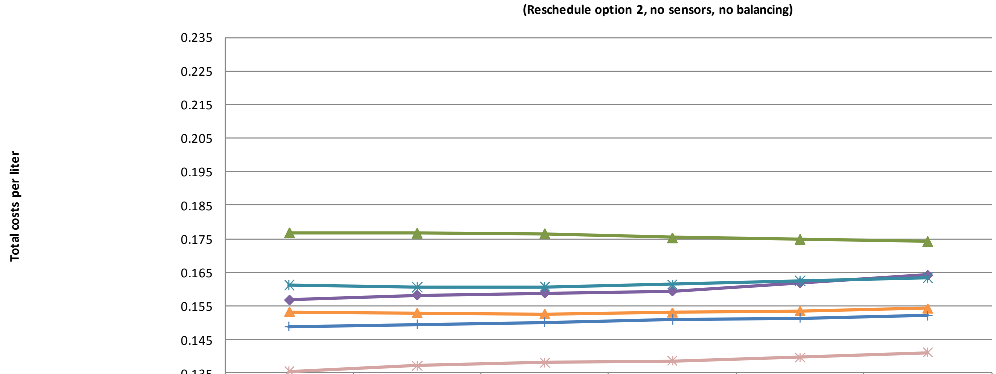


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 1	0.157	0.158	0.163	0.172	0.185	0.201
Must Go Day: 1, May Go Day: 3	0.153	0.154	0.155	0.159	0.168	0.175
Must Go Day: 1, May Go Day: 5	0.136	0.137	0.139	0.146	0.152	0.161
Must Go Day: 2, May Go Day: 1	0.161	0.162	0.164	0.168	0.175	0.186
Must Go Day: 2, May Go Day: 3	0.149	0.149	0.153	0.154	0.160	0.170
Must Go Day: 2, May Go Day: 5	0.177	0.174	0.172	0.173	0.174	0.179

Sinus variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - MayGoFixed: Must Go Days in relation to serval May Go Days under an uniform uncertainty

(Reschedule option 2, no sensors, no balancing)

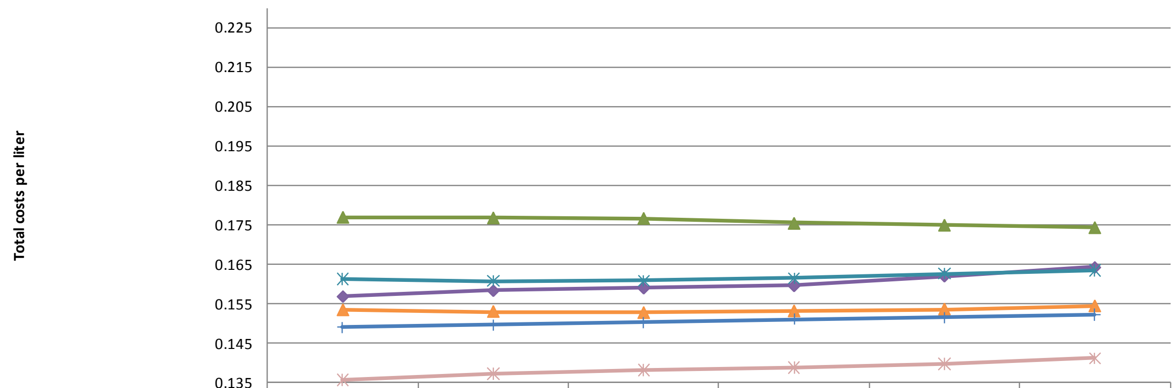


	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 1, May Go Day: 1	0.157	0.158	0.159	0.159	0.162	0.164
Must Go Day: 1, May Go Day: 3	0.153	0.153	0.153	0.153	0.153	0.154
Must Go Day: 1, May Go Day: 5	0.136	0.137	0.138	0.139	0.140	0.141
Must Go Day: 2, May Go Day: 1	0.161	0.161	0.161	0.161	0.163	0.163
Must Go Day: 2, May Go Day: 3	0.149	0.150	0.150	0.151	0.151	0.152
Must Go Day: 2, May Go Day: 5	0.177	0.177	0.177	0.175	0.175	0.174

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - MayGoFixed: Must Go Days in relation to serval May Go Days under with an uncertainty in standard deviation

(Reschedule option 2, no sensors, no balancing)

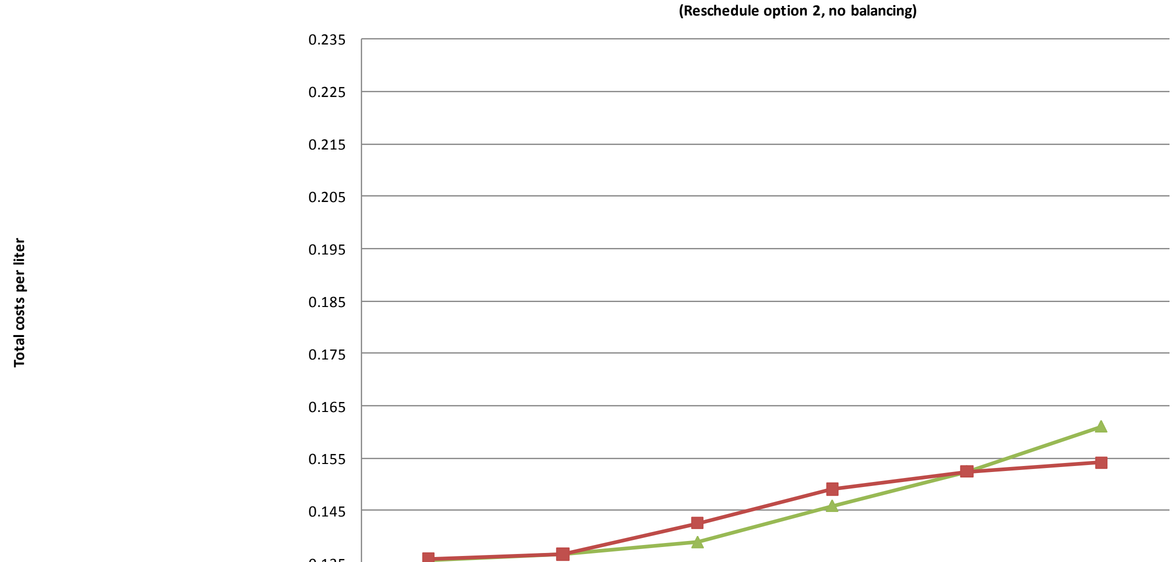


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 1	0.157	0.158	0.159	0.159	0.162	0.164
Must Go Day: 1, May Go Day: 3	0.153	0.153	0.153	0.153	0.153	0.154
Must Go Day: 1, May Go Day: 5	0.136	0.137	0.138	0.139	0.140	0.141
Must Go Day: 2, May Go Day: 1	0.161	0.161	0.161	0.161	0.163	0.163
Must Go Day: 2, May Go Day: 3	0.149	0.150	0.150	0.151	0.151	0.152
Must Go Day: 2, May Go Day: 5	0.177	0.177	0.177	0.175	0.175	0.174

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

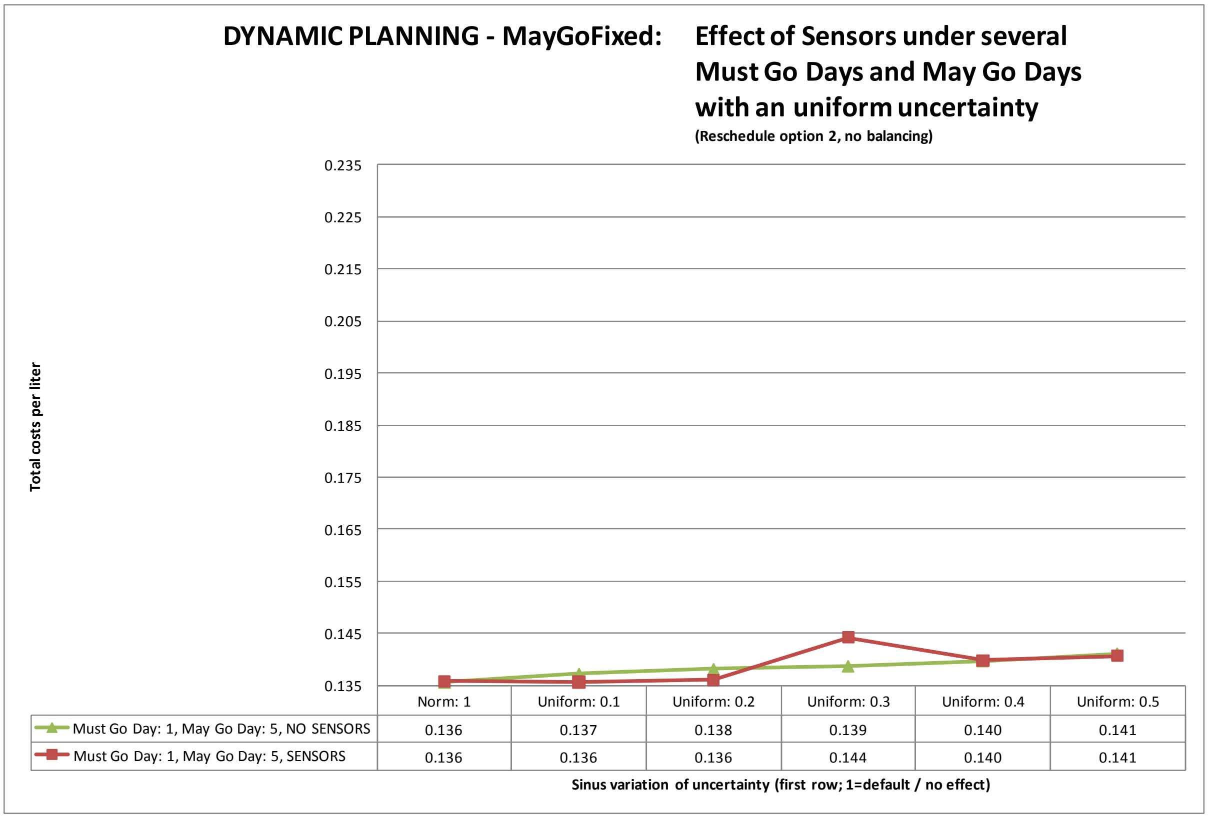
DYNAMIC PLANNING - MayGoFixed: Effect of Sensors under several Must Go Days and May Go Days with a sinus uncertainty

(Reschedule option 2, no balancing)

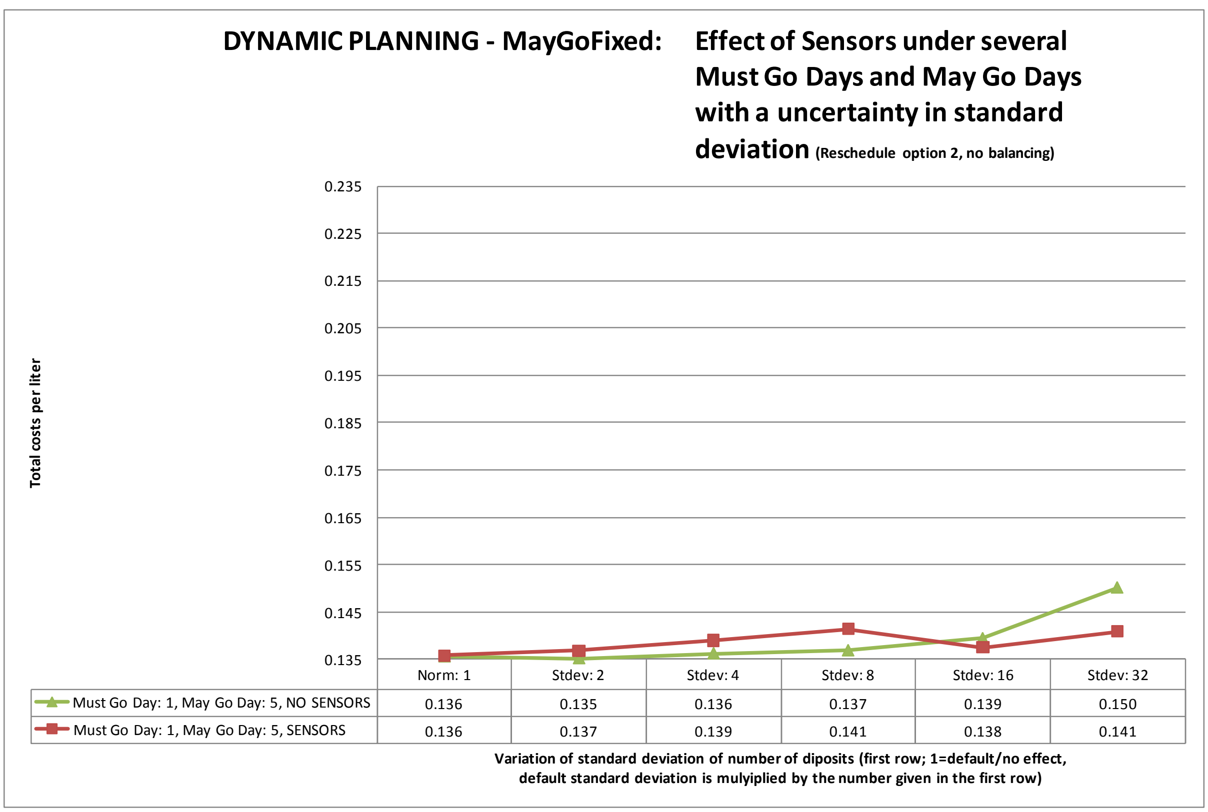


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.136	0.137	0.139	0.146	0.152	0.161
Must Go Day: 1, May Go Day: 5, SENSORS	0.136	0.137	0.143	0.149	0.152	0.154

Sinus variation of uncertainty (first row; 1=default / no effect)



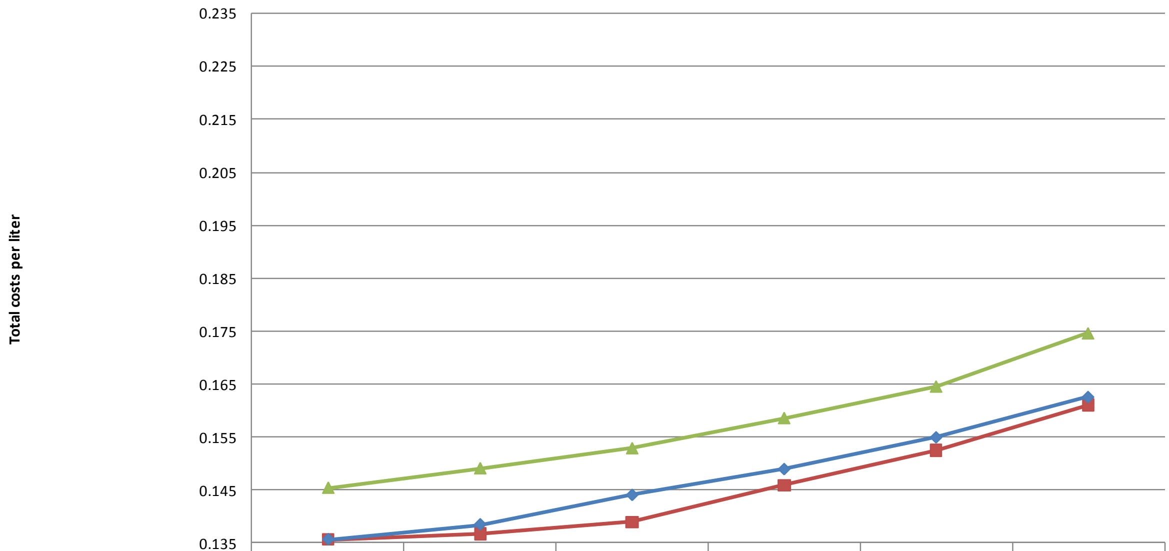
	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.136	0.137	0.138	0.139	0.140	0.141
Must Go Day: 1, May Go Day: 5, SENSORS	0.136	0.136	0.136	0.144	0.140	0.141



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.136	0.135	0.136	0.137	0.139	0.150
Must Go Day: 1, May Go Day: 5, SENSORS	0.136	0.137	0.139	0.141	0.138	0.141

DYNAMIC PLANNING - MayGoFixed: Effect of several rescheduling options under a sinus uncertainty

(Must Go Day: 1, May Go Day: 5, no balancing)

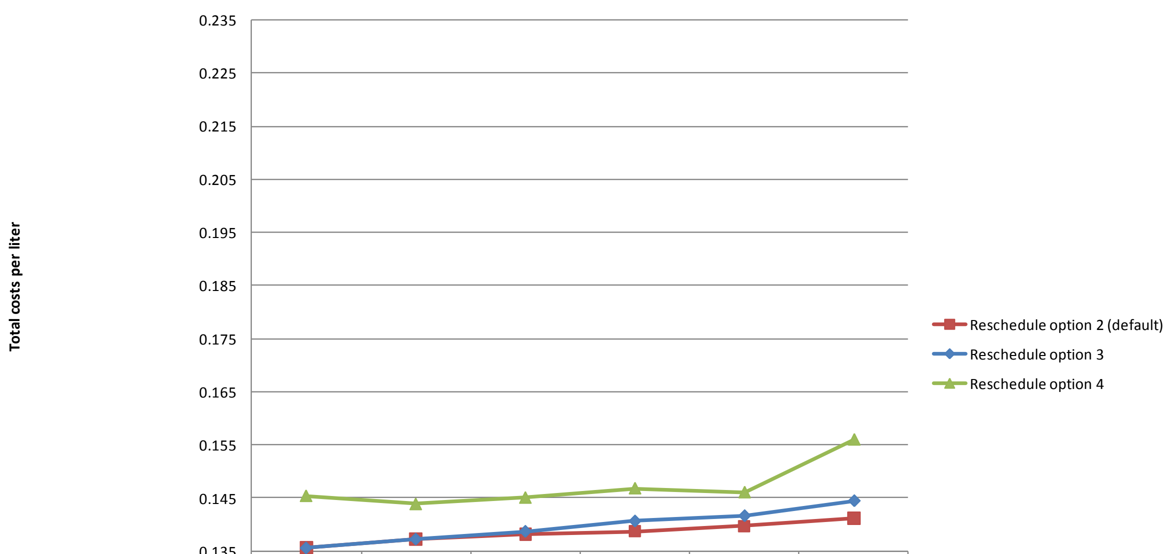


	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Reschedule option 2 (default)	0.136	0.137	0.139	0.146	0.152	0.161
Reschedule option 3	0.136	0.138	0.144	0.149	0.155	0.163
Reschedule option 4	0.145	0.149	0.153	0.159	0.165	0.175

Sinus variation of uncertainty (first row; 1=default / no effect)

DYNAMIC PLANNING - MayGoFixed: Effect of several rescheduling options under a uniform uncertainty

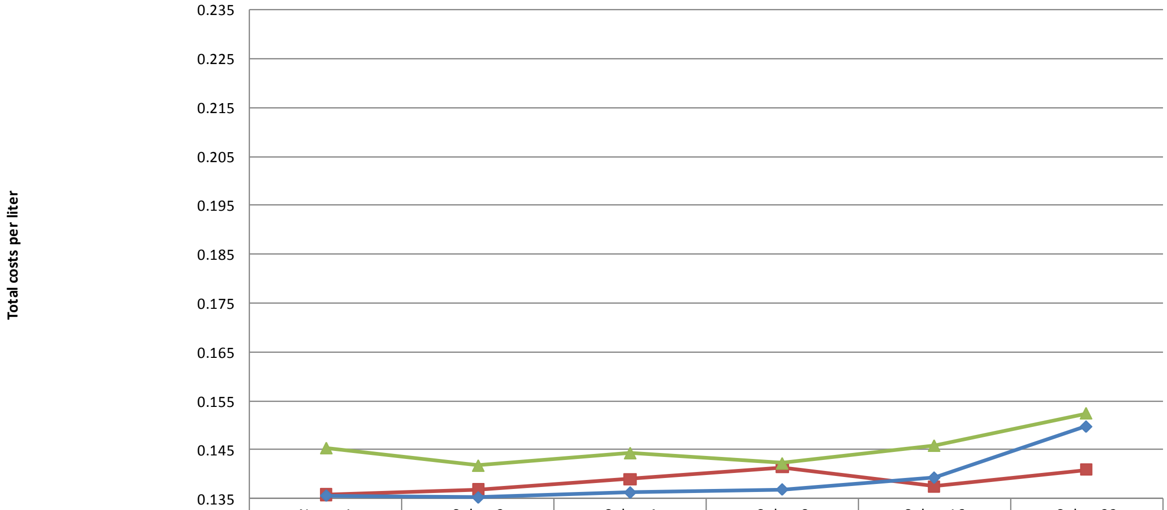
(Must Go Day: 1, May Go Day: 5, no balancing)



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Reschedule option 2 (default)	0.136	0.137	0.138	0.139	0.140	0.141
Reschedule option 3	0.136	0.137	0.139	0.141	0.142	0.144
Reschedule option 4	0.145	0.144	0.145	0.147	0.146	0.156

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

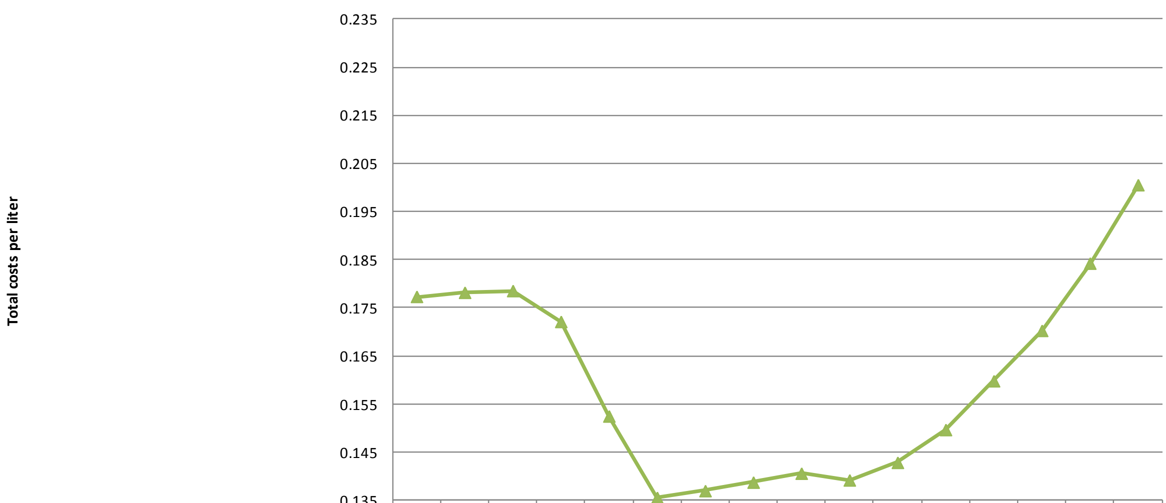
DYNAMIC PLANNING - MayGoFixed: Effect of several rescheduling options under an uncertainty in standard deviation (Must Go Day: 1, May Go Day: 5, no balancing)



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Reschedule option 2 (default)	0.136	0.137	0.139	0.141	0.138	0.141
Reschedule option 3	0.136	0.135	0.136	0.137	0.139	0.150
Reschedule option 4	0.145	0.142	0.144	0.142	0.146	0.152

Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

DYNAMIC PLANNING - MayGoFixed: Experiments with uncertainty in the mean of the number of disposals (no balancing, Must Go Day 1, May Go Day 5, Reschedule oprion 2)

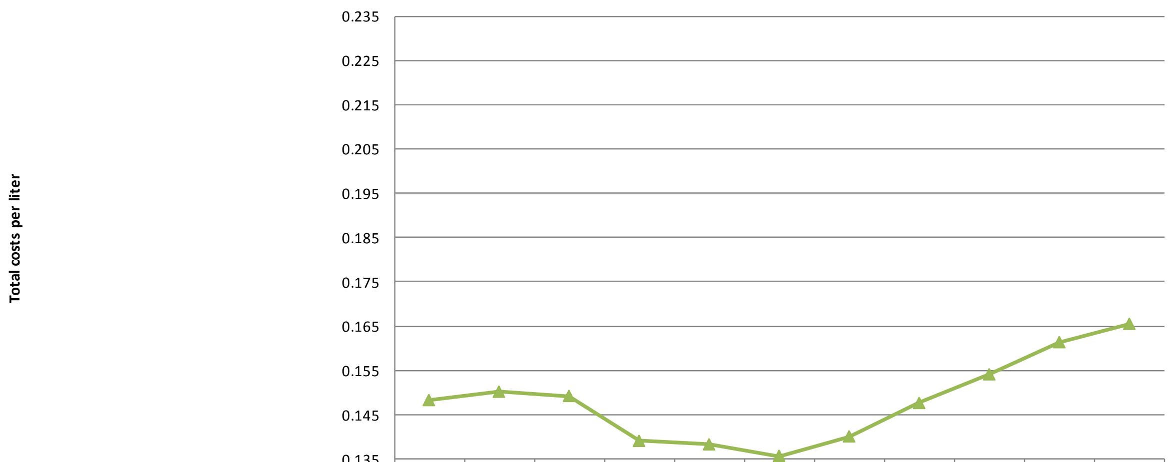


	Mean :0.5	Mean :0.6	Mean :0.7	Mean :0.8	Mean :0.9	Mean :1	Mean :1.1	Mean :1.2	Mean :1.3	Mean :1.4	Mean :1.5	Mean :1.6	Mean :1.7	Mean :1.8	Mean :1.9	Mean :2
Reschedule option 2, NO SENSORS, Must Go Day 1, May Go Day 5	0.177	0.178	0.178	0.172	0.152	0.136	0.137	0.139	0.141	0.139	0.143	0.150	0.160	0.170	0.184	0.200

Mean stands for the average of expected disposits of an individual container. The default mean is given by a gamma distribution (alpha: 1.93, beta: 5.88) that equals 11.35. This mean than is multiplied by the mean factors given in the first row (first row

DYNAMIC PLANNING - MayGoFixed: Experiments with uncertainty in the expected number of disposals (estimation errors)

(no balancing, Must Go Day 1, May Go Day 5, Reschedule oprion 2)

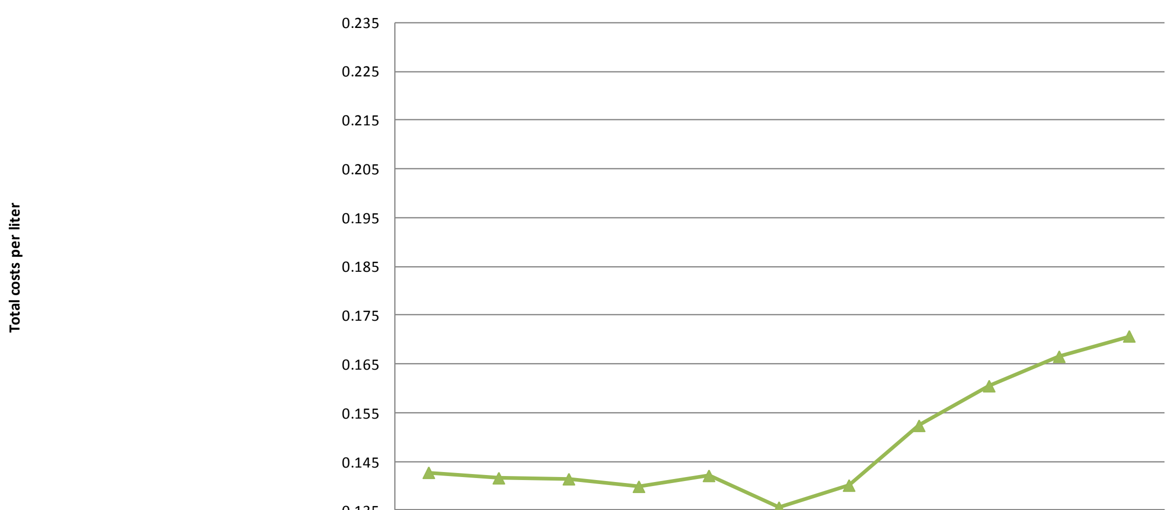


	Expec: 0.75	Expec: 0.8	Expec: 0.85	Expec: 0.9	Expec: 0.95	Expec: 1	Expec: 1.05	Expec: 1.1	Expec: 1.15	Expec: 1.2	Expec: 1.25
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.148	0.150	0.149	0.139	0.138	0.136	0.140	0.148	0.154	0.161	0.166

Variation of estimation of number of diposits (first row; 1=default/no effect, mean measured by the containers is mulyiplied by the number given in the first row, shows the estimation effect on deposits Twente Milieu could make)

DYNAMIC PLANNING - MayGoFixed: Experiments with a deviation of the StaticMax (the percentage emptied conatiners per workday)

(no balancing, Must Go Day 1, May Go Day 5, Reschedule oprion 2)

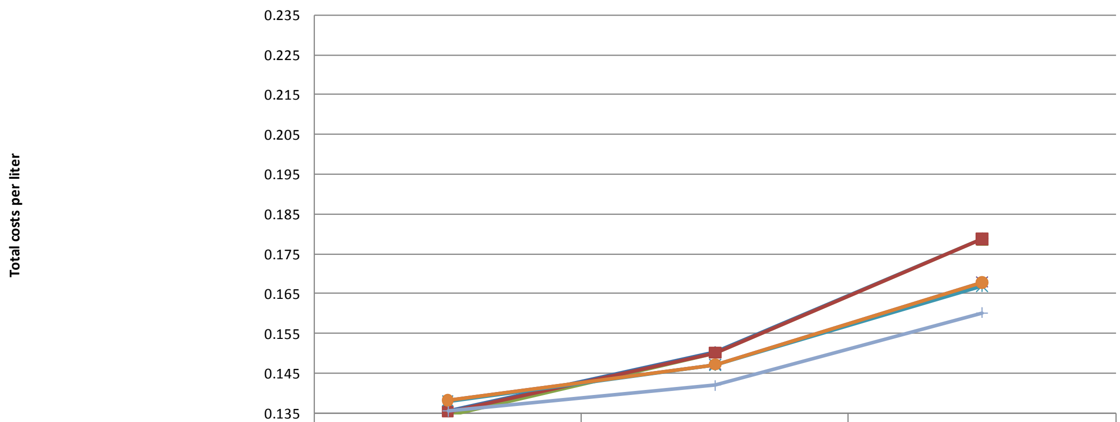


	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.143	0.142	0.141	0.140	0.142	0.136	0.140	0.152	0.160	0.166	0.171

Variation of StaticMax(first row; 1=default/no effect)

700 containers

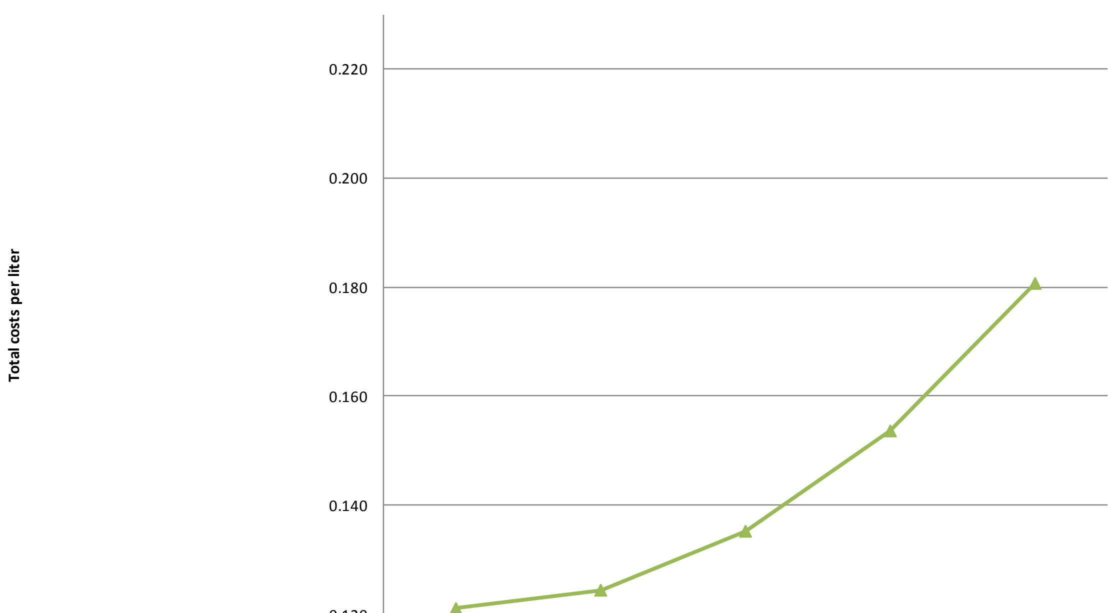
Dynamic MayGoFixed: Experiments with Must Go Days w.r.t. to May Go Days & the effect of sensors (reschedule option 2)



	Norm: 1	Sinus: 0,2	Sinus: 0,4
Must Go Day: 1, May Go Day:1	0.135	0.150	0.179
Must Go Day: 1, May Go Day:3	0.134	0.150	0.179
Must Go Day: 1, May Go Day:5	0.135	0.150	0.179
Must Go Day: 2, May Go Day:1	0.138	0.147	0.168
Must Go Day: 2, May Go Day:3	0.138	0.147	0.167
Must Go Day: 2, May Go Day:5	0.138	0.147	0.168
Must Go Day: 2, May Go Day:5, SENSORS	0.135	0.142	0.160

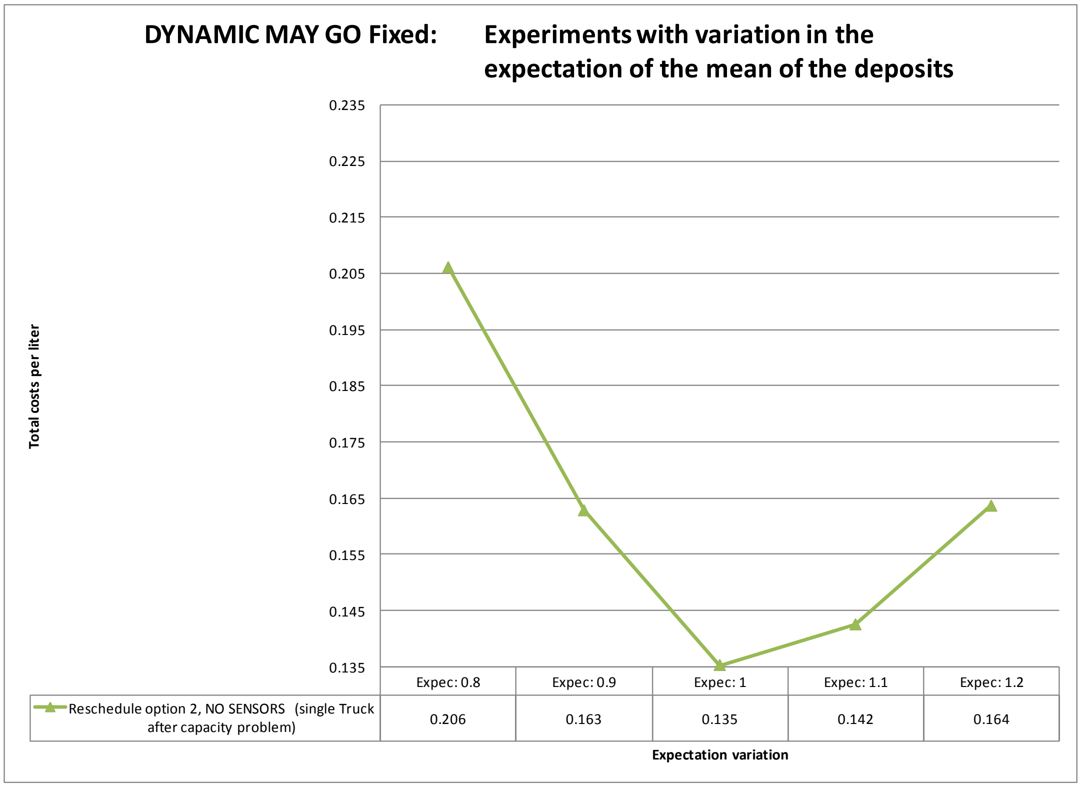
Sinus variation

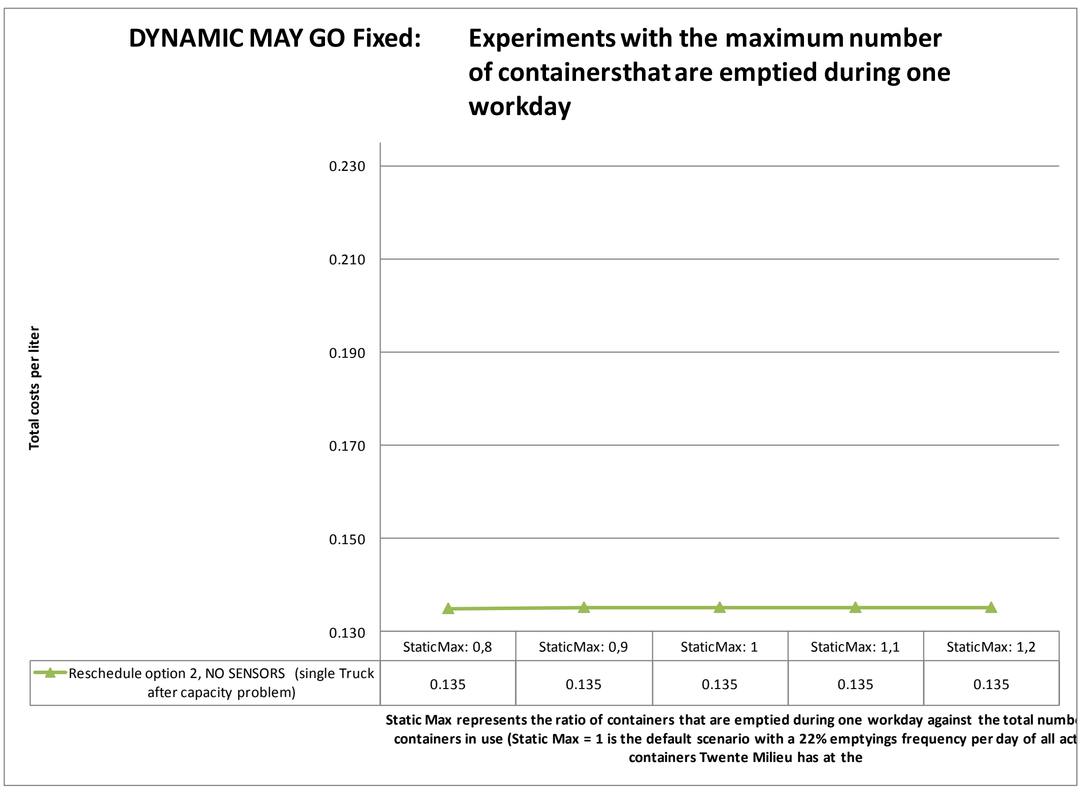
DYNAMIC MAY GO Fixed: Experiments with variation in the mean of the deposits



	Mean: 0,8	Mean: 0,9	Mean: 1	Mean: 1,1	Mean: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.121	0.124	0.135	0.154	0.181

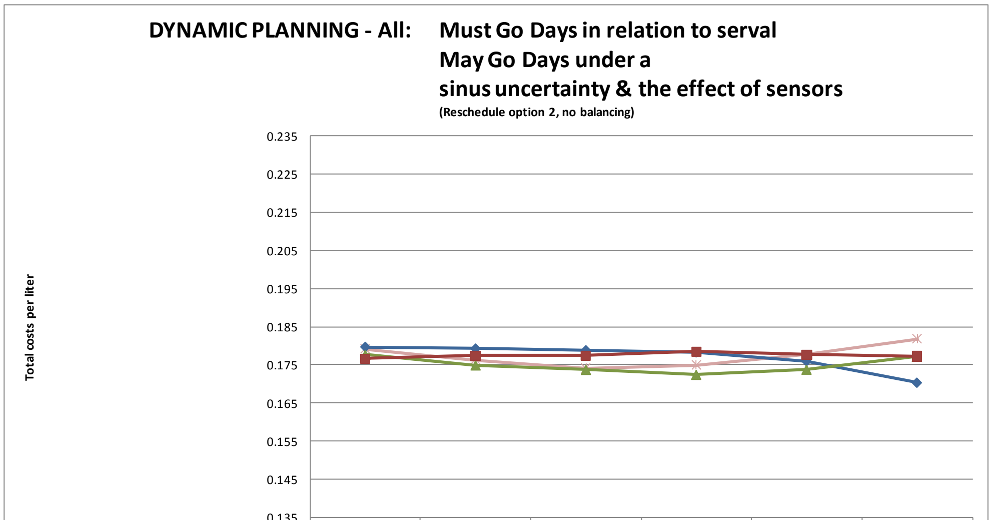
Mean variation


DYNAMIC MAY GO Fixed: Experiments with variation in the expectation of the mean of the deposits
Total costs per liter
0.235
0.225
0.215
0.205
0.195
0.185
0.175
0.165
0.155
0.145
0.135
Expec: 0.8
Expec: 0.9
Expec: 1
Expec: 1.1
Expec: 1.2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.206
0.163
0.135
0.142
0.164
Expectation variation


DYNAMIC MAY GO Fixed: Experiments with the maximum number of containersthat are emptied during one workday
Total costs per liter
0.230
0.210
0.190
0.170
0.150
0.130
StaticMax: 0,8
StaticMax: 0,9
StaticMax: 1
StaticMax: 1,1
StaticMax: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.135
0.135
0.135
0.135
0.135
Static Max represents the ratio of containers that are emptied during one workday against the total numb
containers in use (Static Max = 1 is the default scenario with a 22% emptyings frequency per day of all act
containers Twente Milieu has at the

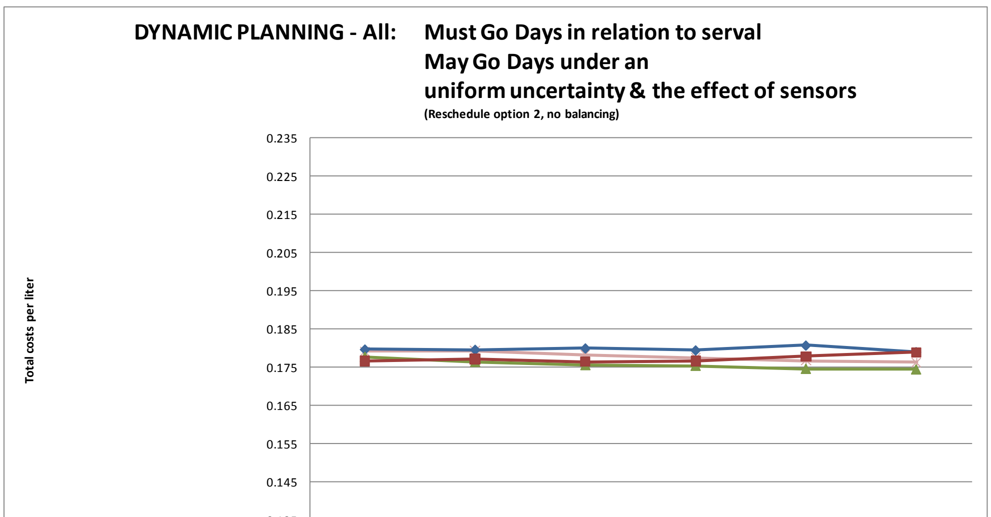
APPENDIX 26
– COMPUTATIONAL RESULTS DYNAMIC PLANNING WITH BALANCING AND MAYGO-JOBS

378 containers



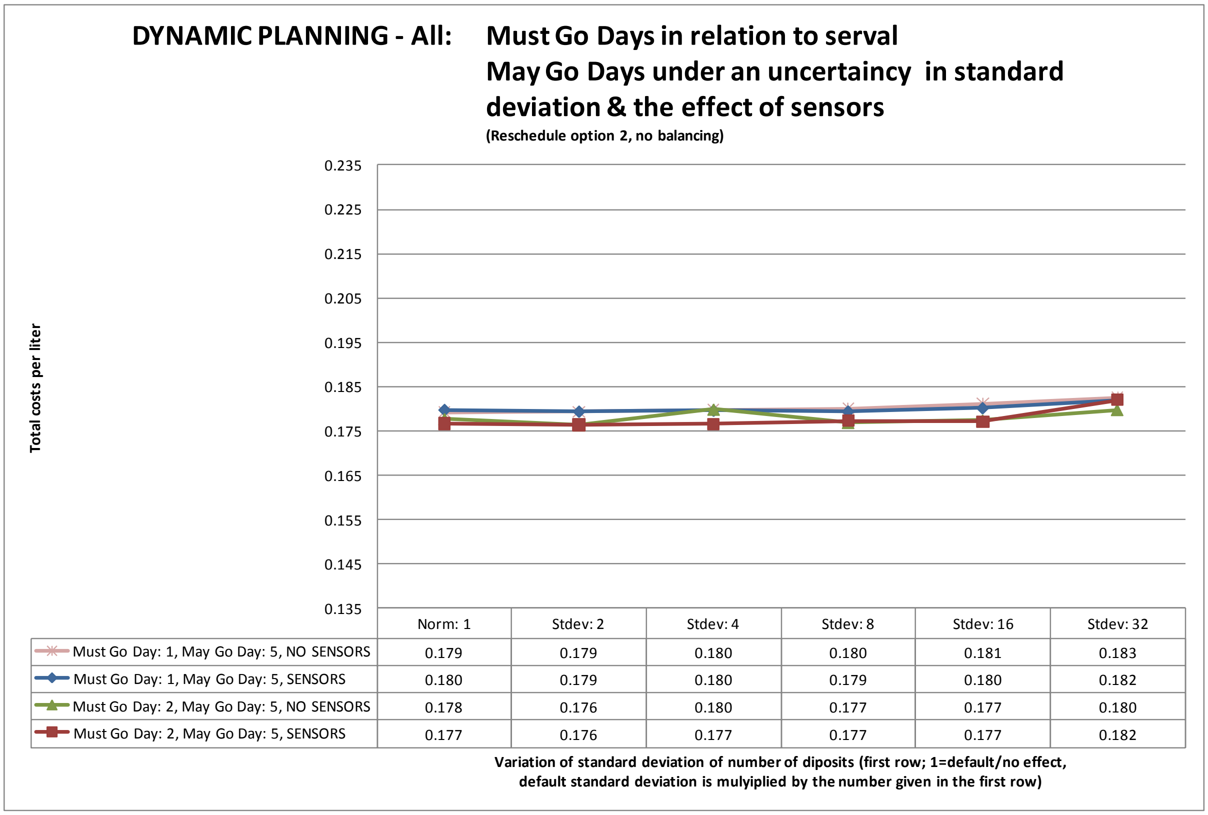
	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.179	0.176	0.174	0.175	0.178	0.182
Must Go Day: 1, May Go Day: 5, SENSORS	0.180	0.179	0.179	0.178	0.176	0.170
Must Go Day: 2, May Go Day: 5, NO SENSORS	0.178	0.175	0.174	0.172	0.174	0.177
Must Go Day: 2, May Go Day: 5, SENSORS	0.177	0.177	0.177	0.178	0.178	0.177

Sinus variation of uncertainty (first row; 1=default / no effect)

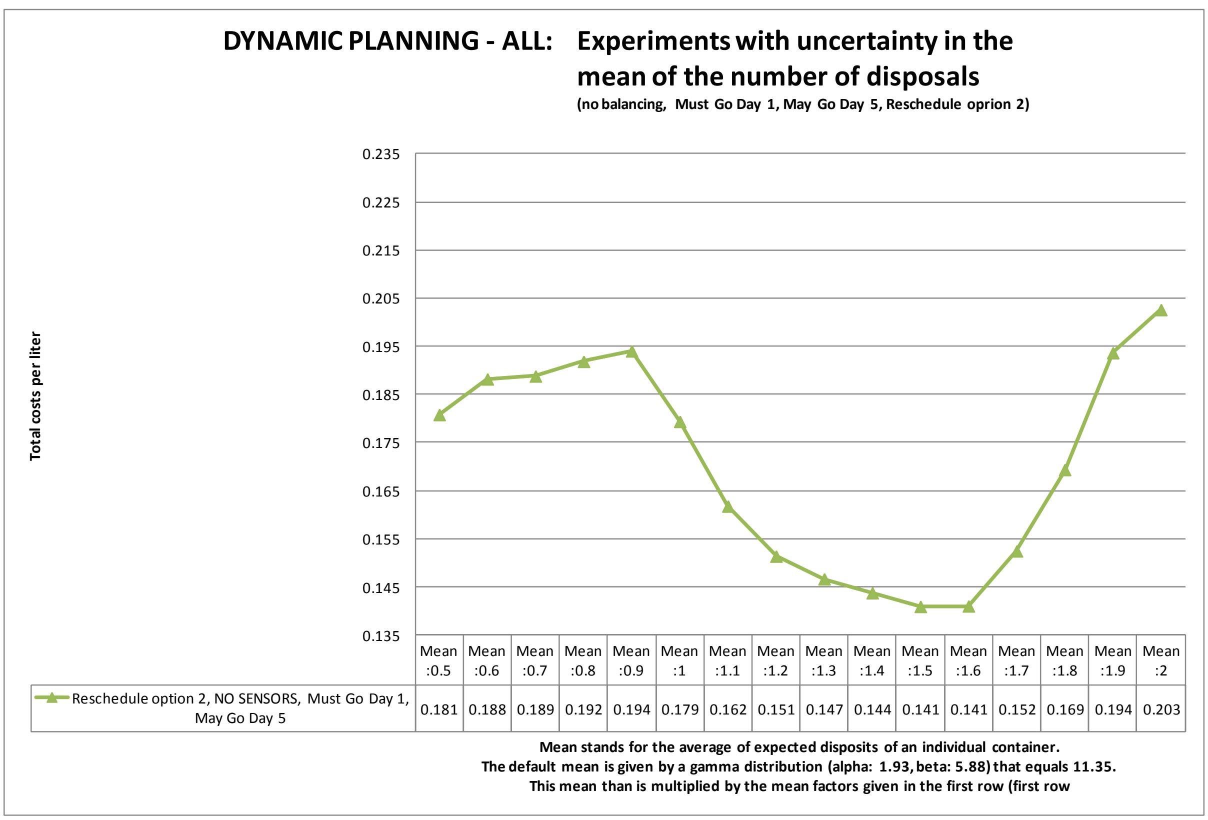


	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.179	0.179	0.178	0.177	0.177	0.176
Must Go Day: 1, May Go Day: 5, SENSORS	0.180	0.180	0.180	0.179	0.181	0.179
Must Go Day: 2, May Go Day: 5, NO SENSORS	0.178	0.176	0.176	0.175	0.175	0.174
Must Go Day: 2, May Go Day: 5, SENSORS	0.177	0.177	0.176	0.177	0.178	0.179

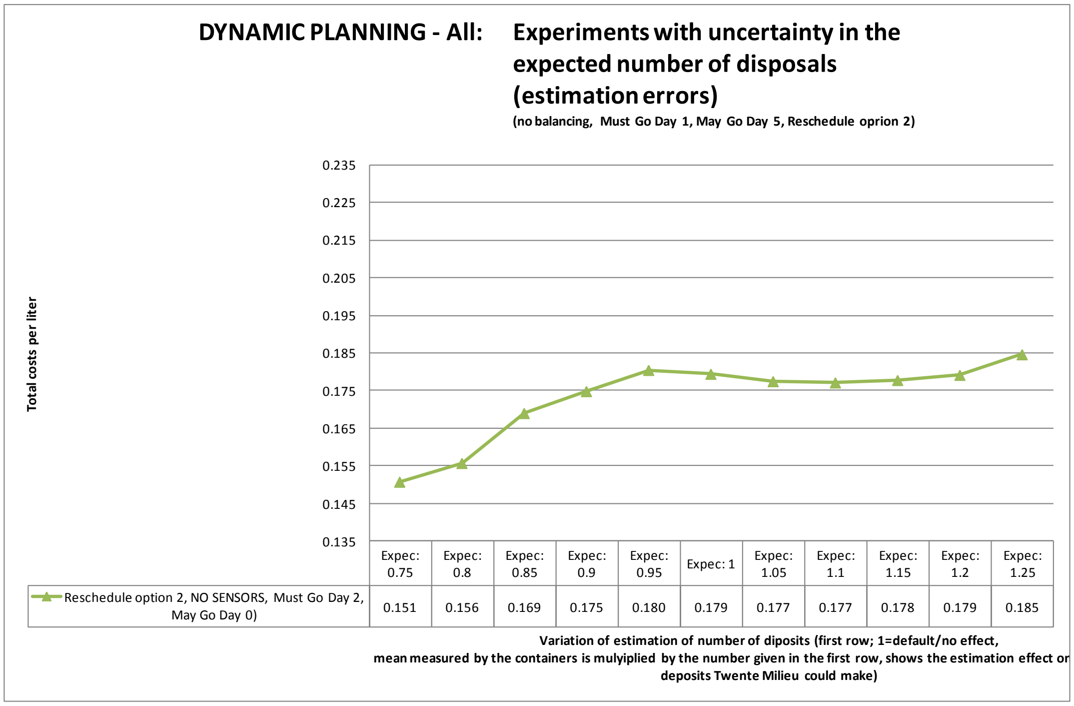
Uniform disposit variation of uncertainty (first row; 1=default / no effect)



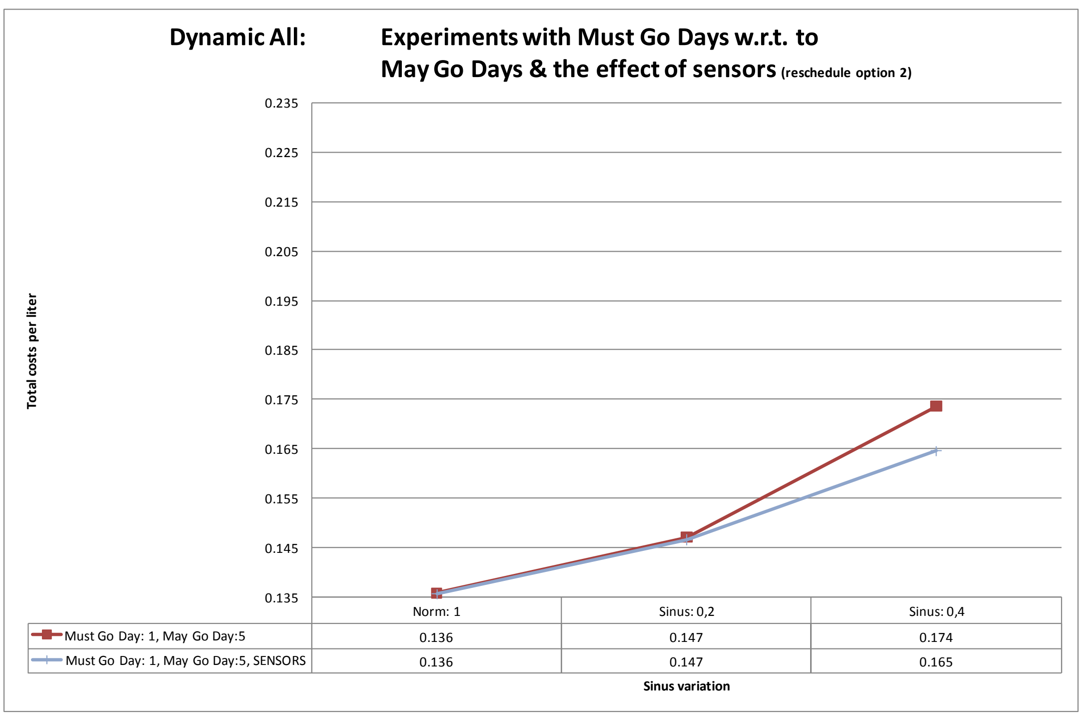
	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.179	0.179	0.180	0.180	0.181	0.183
Must Go Day: 1, May Go Day: 5, SENSORS	0.180	0.179	0.180	0.179	0.180	0.182
Must Go Day: 2, May Go Day: 5, NO SENSORS	0.178	0.176	0.180	0.177	0.177	0.180
Must Go Day: 2, May Go Day: 5, SENSORS	0.177	0.176	0.177	0.177	0.177	0.182

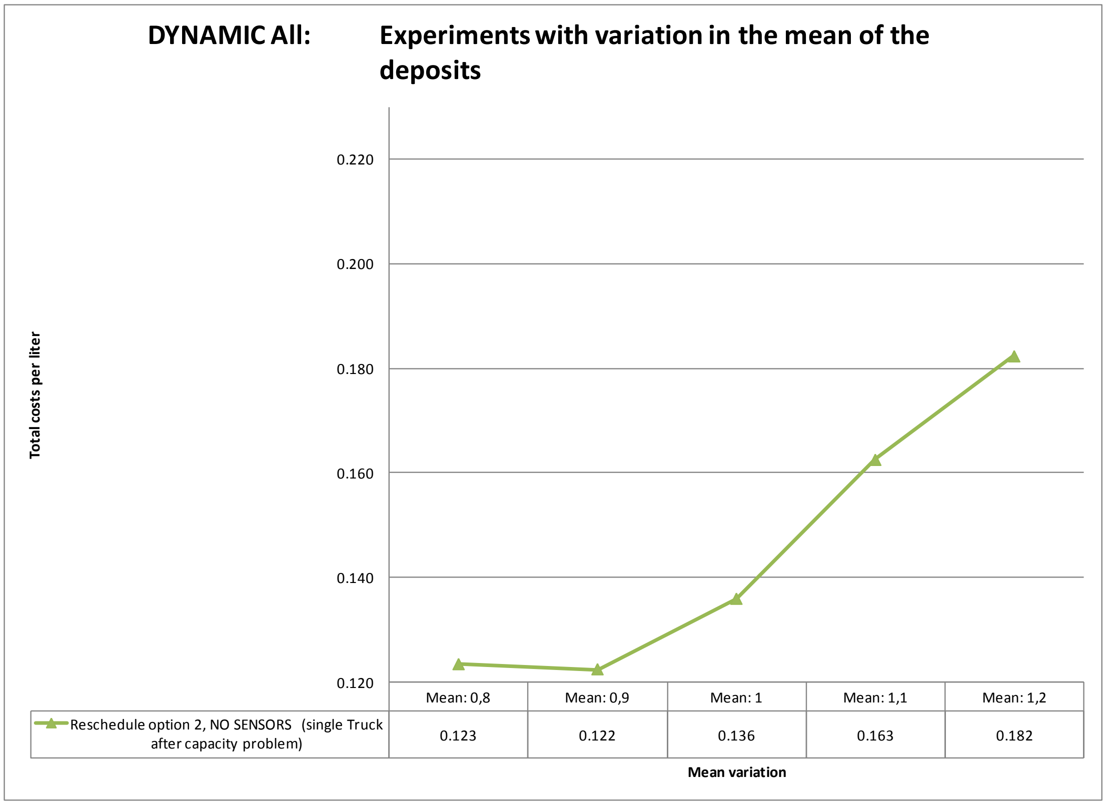


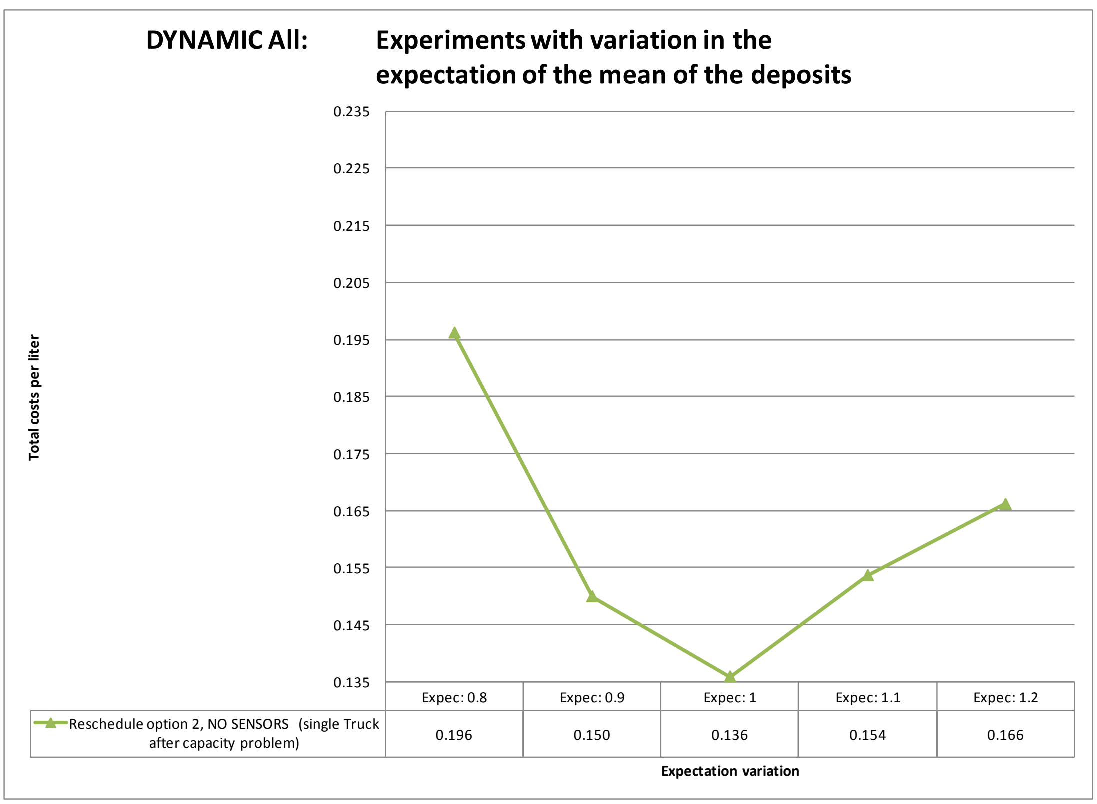
	Mean :0.5	Mean :0.6	Mean :0.7	Mean :0.8	Mean :0.9	Mean :1	Mean :1.1	Mean :1.2	Mean :1.3	Mean :1.4	Mean :1.5	Mean :1.6	Mean :1.7	Mean :1.8	Mean :1.9	Mean :2
Reschedule option 2, NO SENSORS, Must Go Day 1, May Go Day 5	0.181	0.188	0.189	0.192	0.194	0.179	0.162	0.151	0.147	0.144	0.141	0.141	0.152	0.169	0.194	0.203

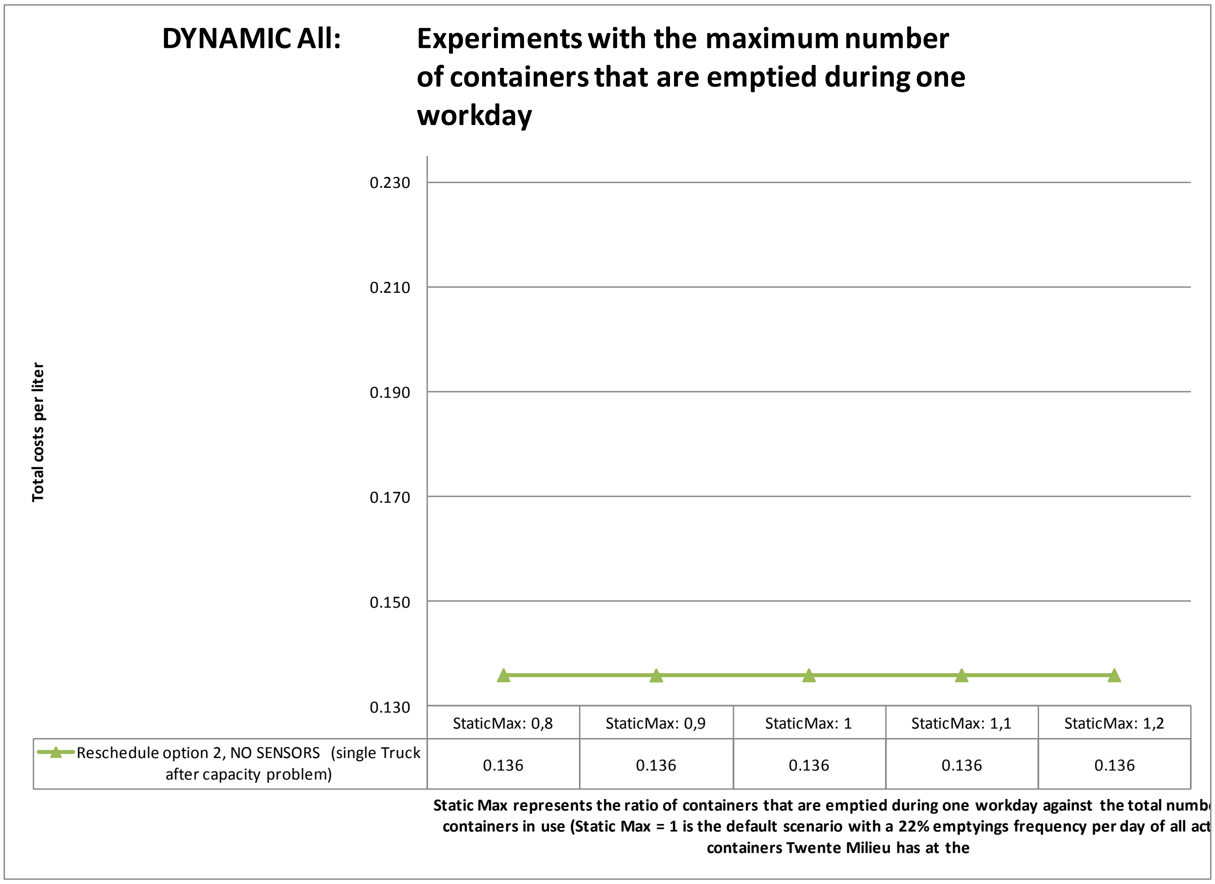


700 containers




DYNAMIC All: Experiments with variation in the mean of the deposits
Total costs per liter
0.220
0.200
0.180
0.160
0.140
0.120
Mean: 0,8
Mean: 0,9
Mean: 1
Mean: 1,1
Mean: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.123
0.122
0.136
0.163
0.182
Mean variation

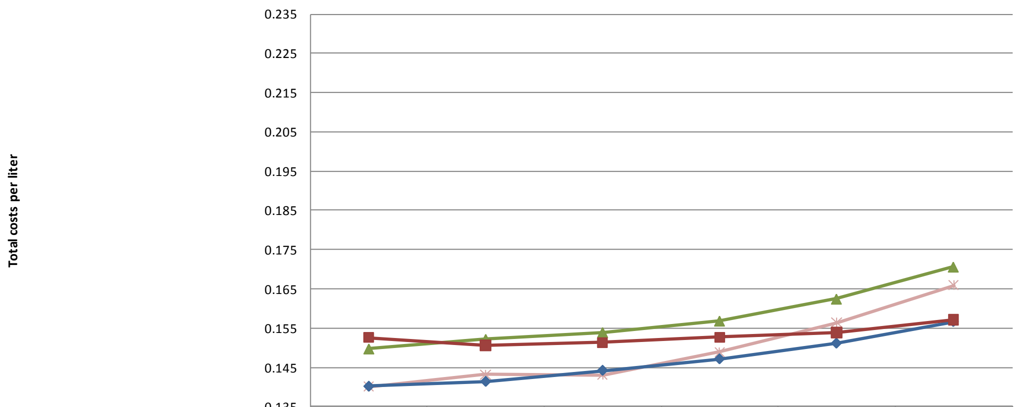

DYNAMIC All: Experiments with variation in the expectation of the mean of the deposits
Total costs per liter
0.235
0.225
0.215
0.205
0.195
0.185
0.175
0.165
0.155
0.145
0.135
Expec: 0.8
Expec: 0.9
Expec: 1
Expec: 1.1
Expec: 1.2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.196
0.150
0.136
0.154
0.166
Expectation variation


DYNAMIC All:
Experiments with the maximum number of containers that are emptied during one workday
Total costs per liter
0.230
0.210
0.190
0.170
0.150
0.130
StaticMax: 0,8
StaticMax: 0,9
StaticMax: 1
StaticMax: 1,1
StaticMax: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.136
0.136
0.136
0.136
0.136
Static Max represents the ratio of containers that are emptied during one workday against the total numb
containers in use (Static Max = 1 is the default scenario with a 22% emptyings frequency per day of all act
containers Twente Milieu has at the

APPENDIX 27
– COMPUTATIONAL RESULTS DYNAMIC PLANNING WITH BALANCING AND FIXED AMOUNT OF MUST AND MAYGO-JOBS

378 containers

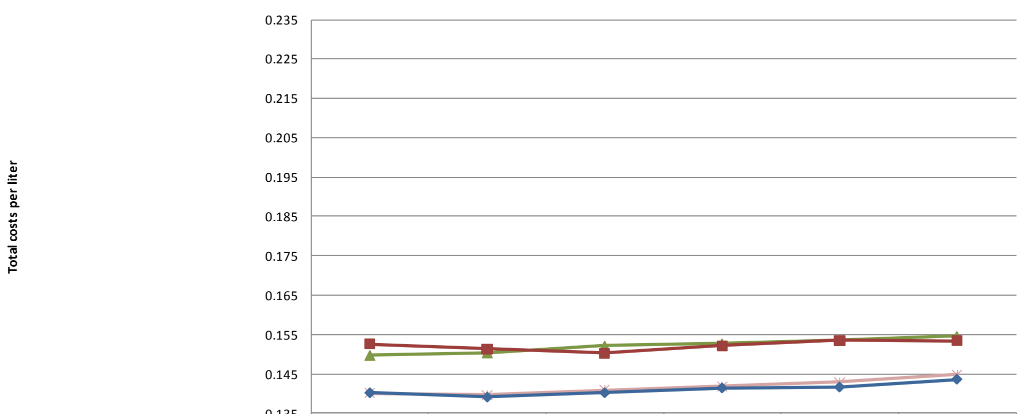
DYNAMIC PLANNING - AllFixed: Must Go Days in relation to serval May Go Days under a sinus uncertainty & the effect of sensors (Reschedule option 2, no balancing)



	Norm: 1	Sinus: 0.1	Sinus: 0.2	Sinus: 0.3	Sinus: 0.4	Sinus: 0.5
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.140	0.143	0.143	0.149	0.156	0.166
Must Go Day: 1, May Go Day: 5, SENSORS	0.140	0.141	0.144	0.147	0.151	0.157
Must Go Day: 2, May Go Day: 5, NO SENSORS	0.150	0.152	0.154	0.157	0.162	0.171
Must Go Day: 2, May Go Day: 5, SENSORS	0.153	0.151	0.151	0.153	0.154	0.157

Sinus variation of uncertainty (first row; 1=default / no effect)

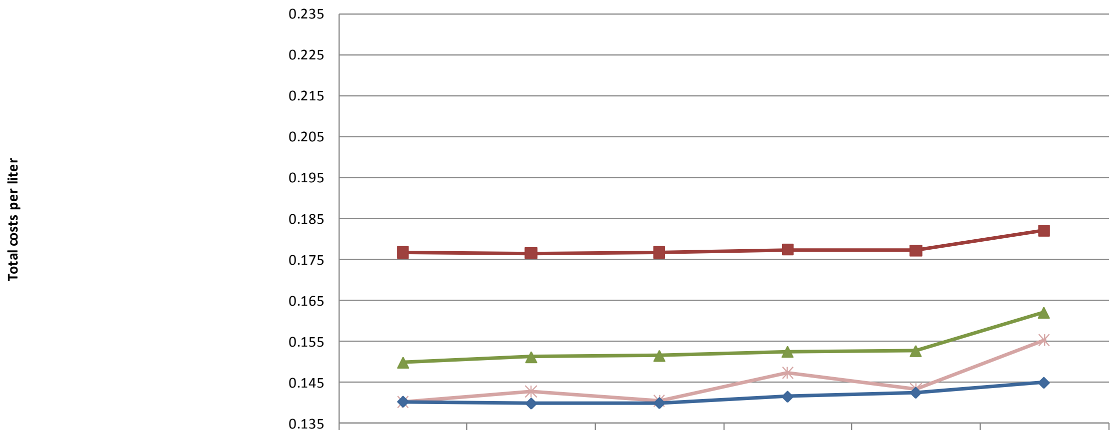
DYNAMIC PLANNING - AllFixed: Must Go Days in relation to serval May Go Days under an uniform uncertainty & the effect of sensors (Reschedule option 2, no balancing)



	Norm: 1	Uniform: 0.1	Uniform: 0.2	Uniform: 0.3	Uniform: 0.4	Uniform: 0.5
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.140	0.140	0.141	0.142	0.143	0.145
Must Go Day: 1, May Go Day: 5, SENSORS	0.140	0.139	0.140	0.141	0.142	0.144
Must Go Day: 2, May Go Day: 5, NO SENSORS	0.150	0.150	0.152	0.153	0.154	0.155
Must Go Day: 2, May Go Day: 5, SENSORS	0.153	0.151	0.150	0.152	0.153	0.153

Uniform disposit variation of uncertainty (first row; 1=default / no effect)

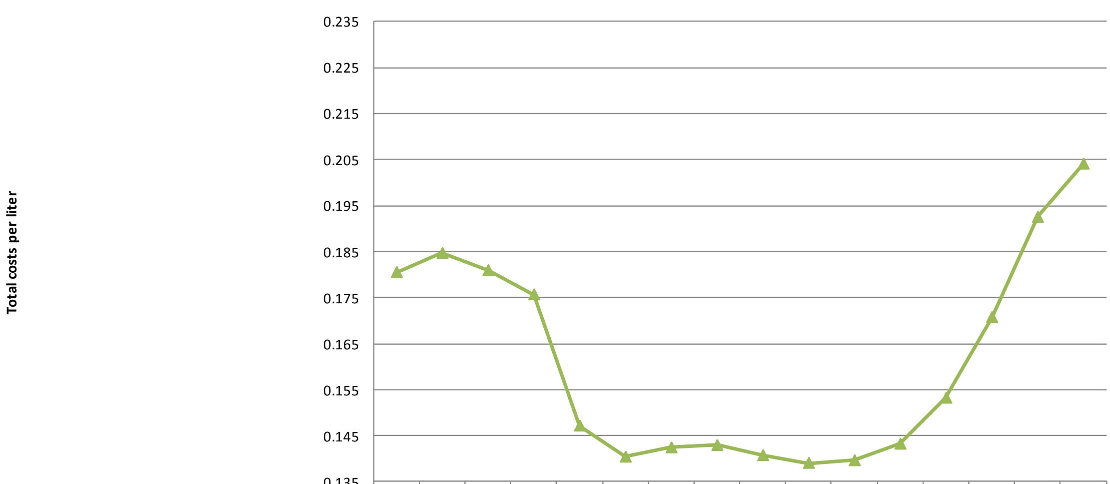
DYNAMIC PLANNING - AllFixed: Must Go Days in relation to serval May Go Days under an uncertaincy in standard deviation & the effect of sensors (Reschedule option 2, no balancing)



	Norm: 1	Stdev: 2	Stdev: 4	Stdev: 8	Stdev: 16	Stdev: 32
Must Go Day: 1, May Go Day: 5, NO SENSORS	0.140	0.143	0.140	0.147	0.143	0.155
Must Go Day: 1, May Go Day: 5, SENSORS	0.140	0.140	0.140	0.141	0.142	0.145
Must Go Day: 2, May Go Day: 5, NO SENSORS	0.150	0.151	0.151	0.152	0.153	0.162
Must Go Day: 2, May Go Day: 5, SENSORS	0.177	0.176	0.177	0.177	0.177	0.182

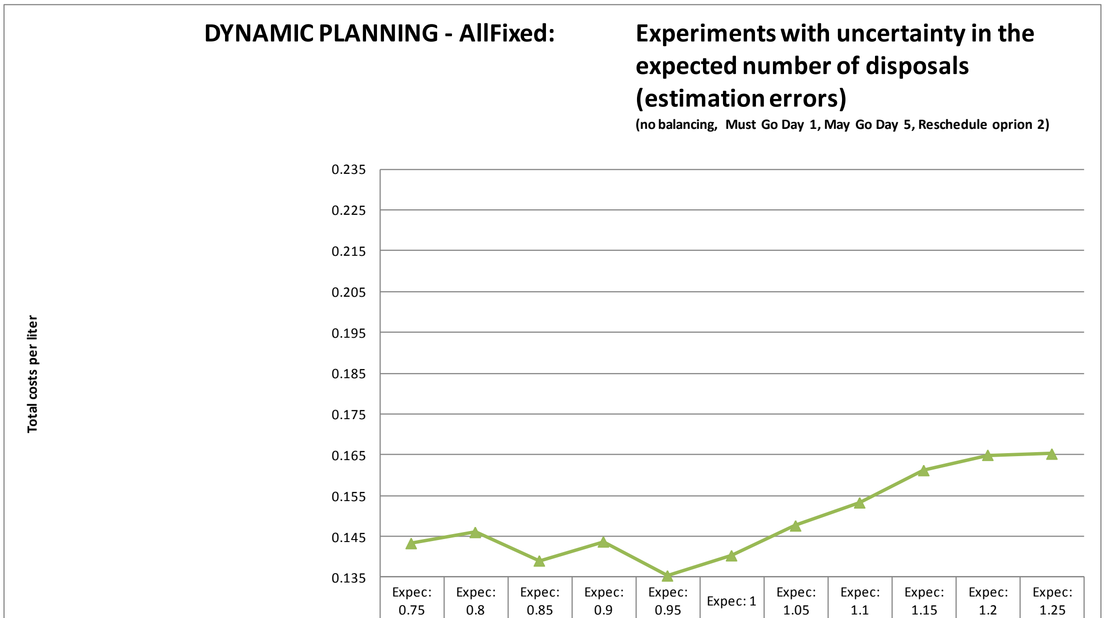
Variation of standard deviation of number of diposits (first row; 1=default/no effect, default standard deviation is mulyiplied by the number given in the first row)

DYNAMIC PLANNING - AllFixed: Experiments with uncertainty in the mean of the number of disposals (no balancing, Must Go Day 1, May Go Day 5, Reschedule oprion 2)

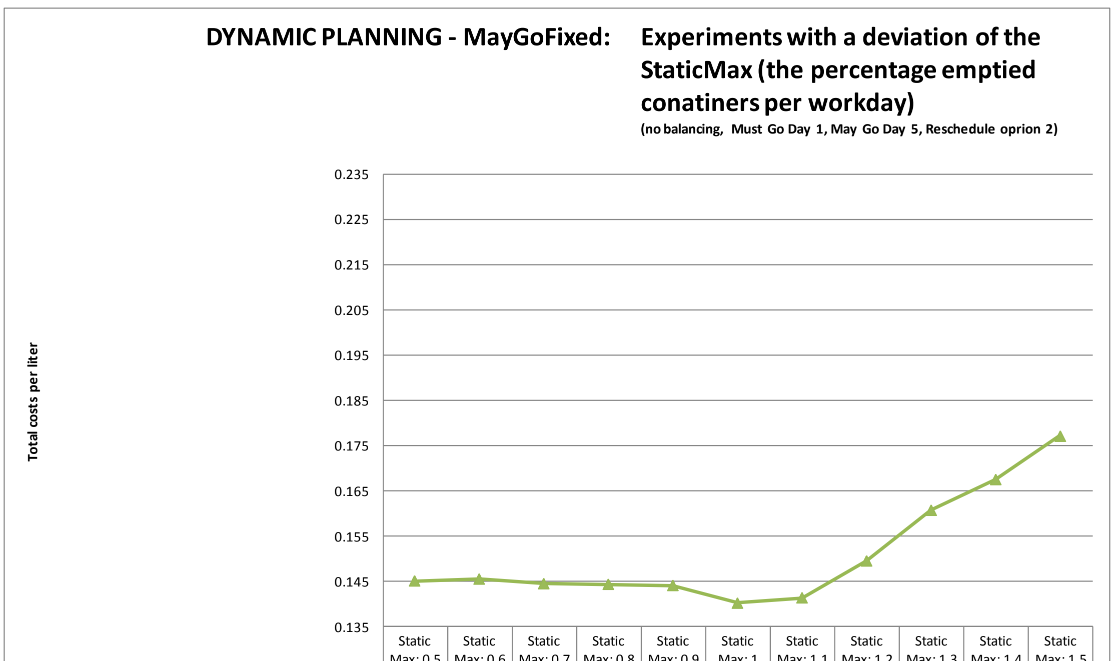


	Mean :0.5	Mean :0.6	Mean :0.7	Mean :0.8	Mean :0.9	Mean :1	Mean :1.1	Mean :1.2	Mean :1.3	Mean :1.4	Mean :1.5	Mean :1.6	Mean :1.7	Mean :1.8	Mean :1.9	Mean :2
Reschedule option 2, NO SENSORS, Must Go Day 1, May Go Day 5	0.181	0.185	0.181	0.176	0.147	0.140	0.142	0.143	0.141	0.139	0.140	0.143	0.153	0.171	0.193	0.204

Mean stands for the average of expected disposits of an individual container.
The default mean is given by a gamma distribution (alpha: 1.93, beta: 5.88) that equals 11.35.
This mean than is multiplied by the mean factors given in the first row (first row

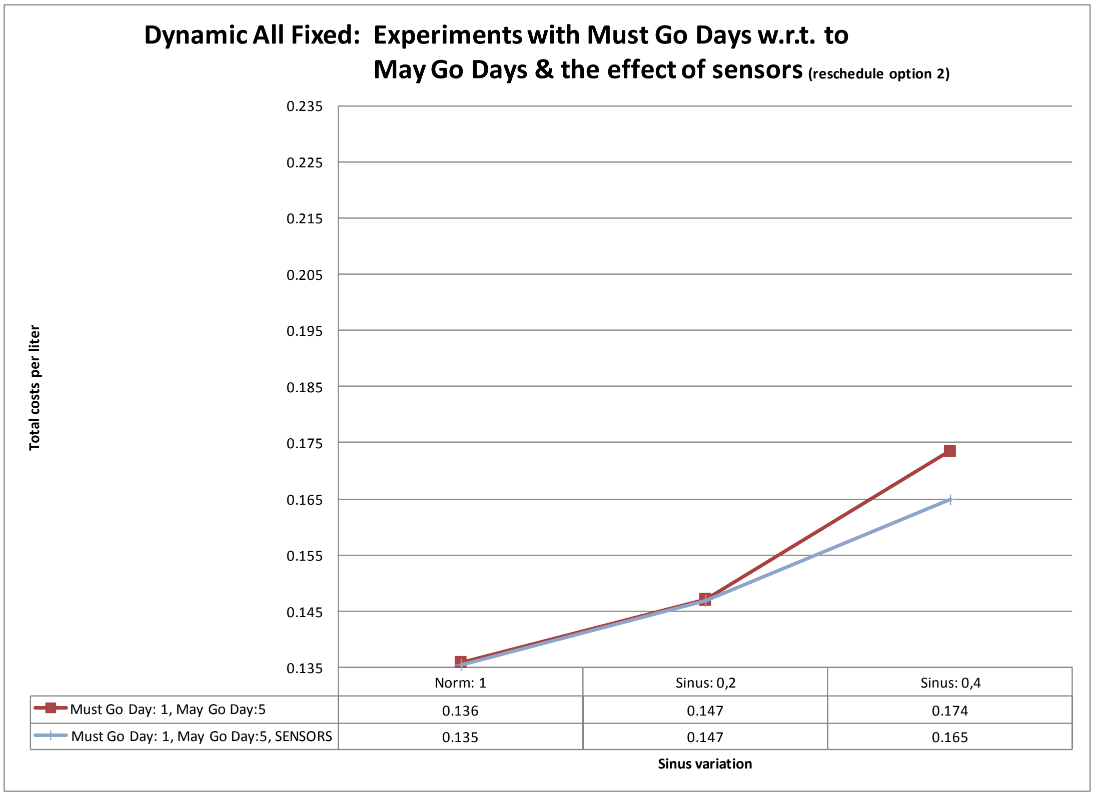


	Expec: 0.75	Expec: 0.8	Expec: 0.85	Expec: 0.9	Expec: 0.95	Expec: 1	Expec: 1.05	Expec: 1.1	Expec: 1.15	Expec: 1.2	Expec: 1.25
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.143	0.146	0.139	0.144	0.135	0.140	0.148	0.153	0.161	0.165	0.165

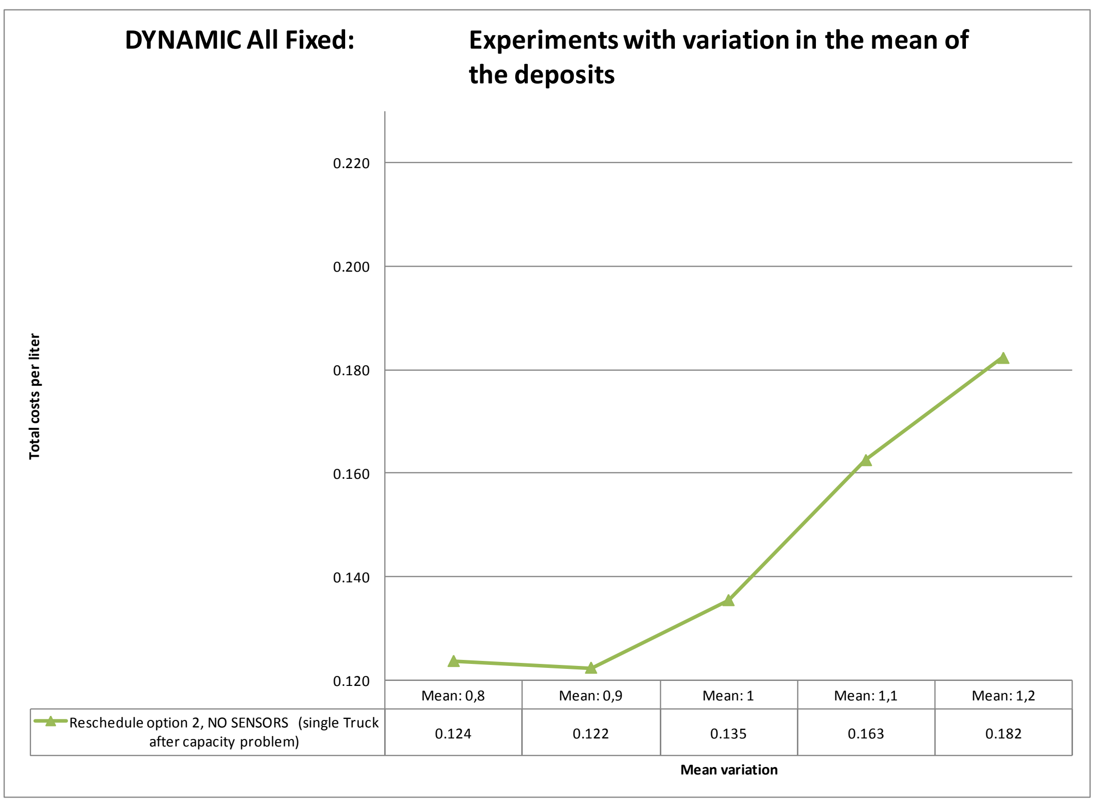


	Static Max: 0.5	Static Max: 0.6	Static Max: 0.7	Static Max: 0.8	Static Max: 0.9	Static Max: 1	Static Max: 1.1	Static Max: 1.2	Static Max: 1.3	Static Max: 1.4	Static Max: 1.5
Reschedule option 2, NO SENSORS, Must Go Day 2, May Go Day 0)	0.145	0.145	0.144	0.144	0.144	0.140	0.141	0.149	0.161	0.167	0.177

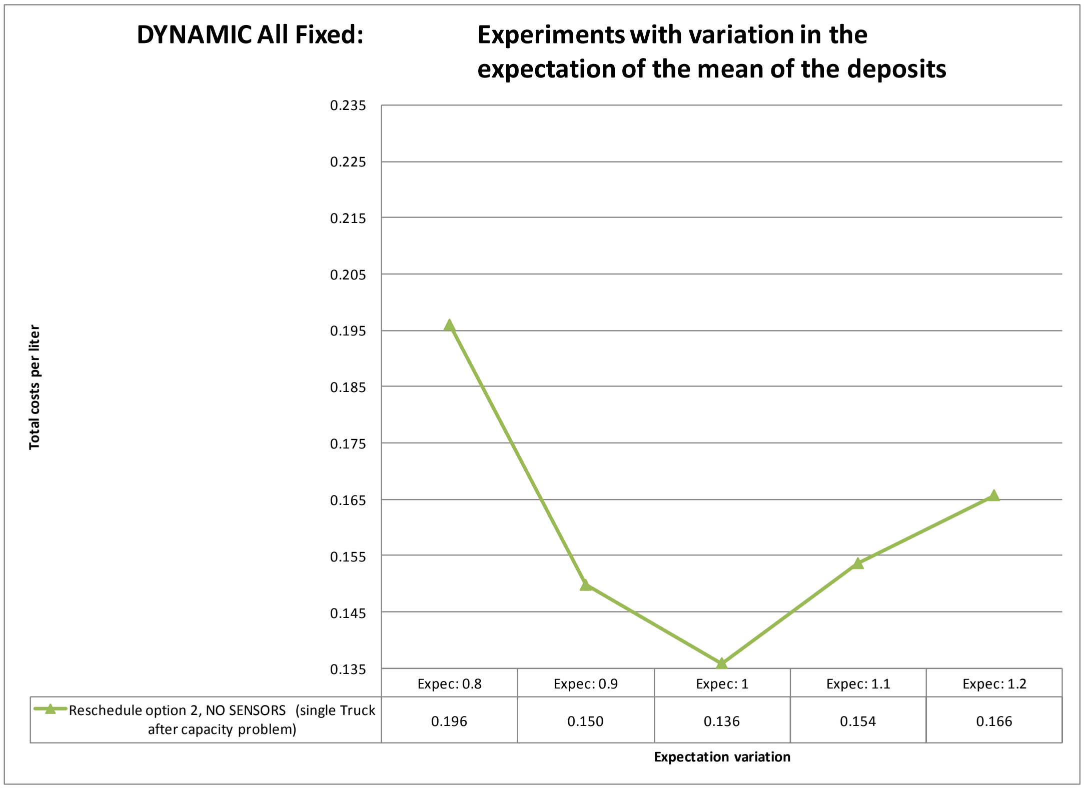
700 containers

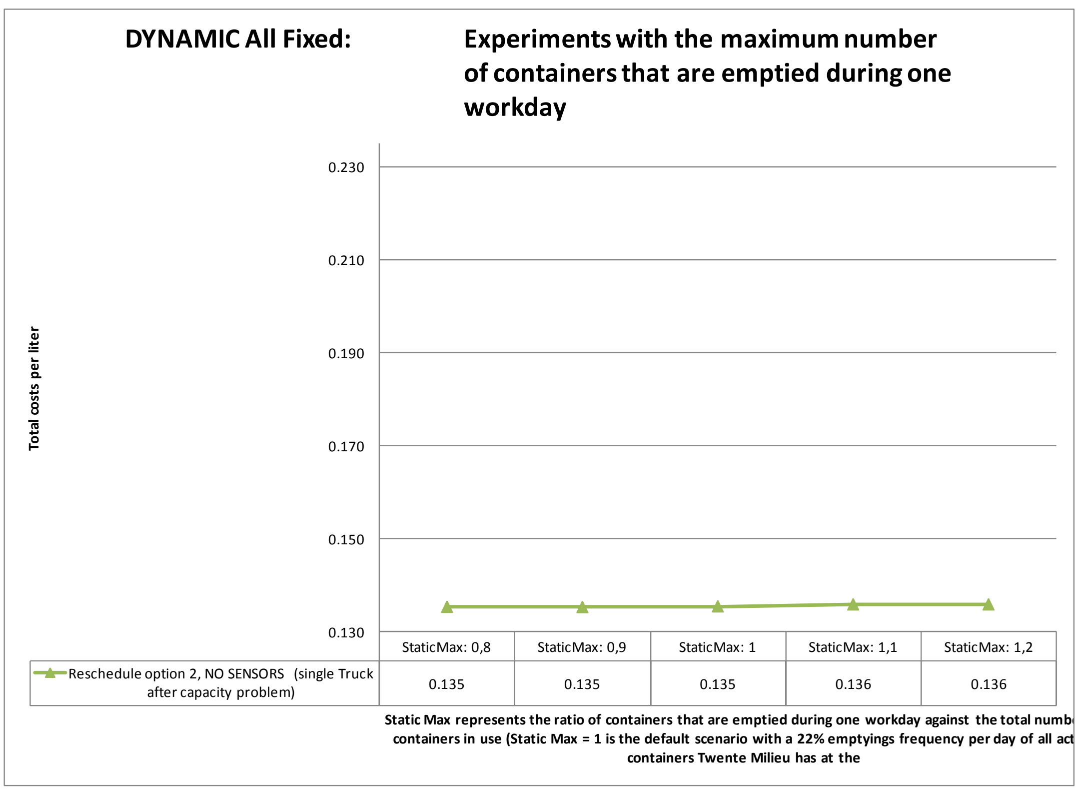


	Norm: 1	Sinus: 0,2	Sinus: 0,4
Must Go Day: 1, May Go Day:5	0.136	0.147	0.174
Must Go Day: 1, May Go Day:5, SENSORS	0.135	0.147	0.165



	Mean: 0,8	Mean: 0,9	Mean: 1	Mean: 1,1	Mean: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)	0.124	0.122	0.135	0.163	0.182


DYNAMIC All Fixed:
Experiments with variation in the expectation of the mean of the deposits
Total costs per liter
0.235
0.225
0.215
0.205
0.195
0.185
0.175
0.165
0.155
0.145
0.135
Expec: 0.8
Expec: 0.9
Expec: 1
Expec: 1.1
Expec: 1.2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.196
0.150
0.136
0.154
0.166
Expectation variation


DYNAMIC All Fixed:
Experiments with the maximum number of containers that are emptied during one workday
Total costs per liter
0.230
0.210
0.190
0.170
0.150
0.130
StaticMax: 0,8
StaticMax: 0,9
StaticMax: 1
StaticMax: 1,1
StaticMax: 1,2
Reschedule option 2, NO SENSORS (single Truck after capacity problem)
0.135
0.135
0.135
0.136
0.136
Static Max represents the ratio of containers that are emptied during one workday against the total numb
containers in use (Static Max = 1 is the default scenario with a 22% emptyings frequency per day of all act
containers Twente Milieu has at the

Appendix 28 – Waste volume determination (Formulas)

Mathematical formula for waste volume determination in m^3

$$\boldsymbol{Container\ fill\ rate\ in\ \%\ (hW, hT, sT, Mh, dB, hB, dNoB, dWithB)}$$

$$= \left\{ \boldsymbol{if\ \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) \leq hB} \rightarrow 100 * \left(\left(\frac{1}{3} * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \left(2 * dNoB^2 + 2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right) + dNoB \right.\right.\right.$$

$$\left. + \left(2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2 \right) / 10^6 + \left(\frac{1}{3} * hB * (dNoB^2 + dNoB * dWithB + dWithB^2)\right) / 10^6$$

$$+ \left(\frac{1}{3} * \left(\frac{hT * hW}{Mh}\right) * sT^2 + sT * dNoB + \left(2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2 \right) + dNoB$$

$$\left. + \left(2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * tan\left(\frac{dB}{hB}\right)\right)^2 \right) / 10^6 \right)$$

$$/ \left(\left(\frac{1}{3} * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \left(2 * dNoB^2 + 2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right) + dNoB \right.\right.$$

$$\left. + \left(2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2 \right) / 10^6 + \left(\frac{1}{3} * hB * (dNoB^2 + dNoB * dWithB + dWithB^2)\right) / 10^6$$

$$+ \left(\frac{1}{3} * \left(\frac{hT * Mh}{Mh}\right) * sT^2 + sT * dNoB + \left(2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2 \right) + dNoB$$

$$\left. + \left(2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * tan\left(\frac{dB}{hB}\right)\right)^2 \right) / 10^6 \right) \right.$$

Mathematical formula for container fill rate in % (1/2)

$$\boldsymbol{Container\ fill\ rate\ in}\ \%\ (\boldsymbol{hW}, \boldsymbol{hT}, \boldsymbol{sT}, \boldsymbol{Mh}, \boldsymbol{dB}, \boldsymbol{hB}, \boldsymbol{dNoB}, \boldsymbol{dWithB})$$

$$= \begin{cases} \boldsymbol{if} \left(\boldsymbol{hW} - \left(\frac{\boldsymbol{hT} * \boldsymbol{hW}}{\boldsymbol{Mh}}\right)\right) \leq \boldsymbol{hB} \rightarrow 100 * \Bigg(\Bigg(\frac{1}{3} * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \Bigg(2 * dNoB^2 + 2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\Bigg) + dNoB \\ + \left(2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2\Bigg)/10^6 + \left(\frac{1}{3} * hB * (dNoB^2 + dNoB * dWithB + dWithB^2)\right)/10^6 \\ + \Bigg(\frac{1}{3} * \left(\frac{hT * hW}{Mh}\right) * sT^2 + sT * dNoB + \left(2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2 + dNoB \\ + \left(2 * \left(hW - \left(\frac{hT * hW}{Mh}\right)\right) * tan\left(\frac{dB}{hB}\right)\right)^2\Bigg)/10^6\Bigg) \\ /\Bigg(\Bigg(\frac{1}{3} * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \Bigg(2 * dNoB^2 + 2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\Bigg) + dNoB \\ + \left(2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2\Bigg)/10^6 + \left(\frac{1}{3} * hB * (dNoB^2 + dNoB * dWithB + dWithB^2)\right)/10^6 \\ + \Bigg(\frac{1}{3} * \left(\frac{hT * Mh}{Mh}\right) * sT^2 + sT * dNoB + \left(2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * \tan\left(\frac{dB}{hB}\right)\right)^2 + dNoB \\ + \left(2 * \left(Mh - \left(\frac{hT * Mh}{Mh}\right)\right) * tan\left(\frac{dB}{hB}\right)\right)^2\Bigg)/10^6\Bigg) \end{cases}$$

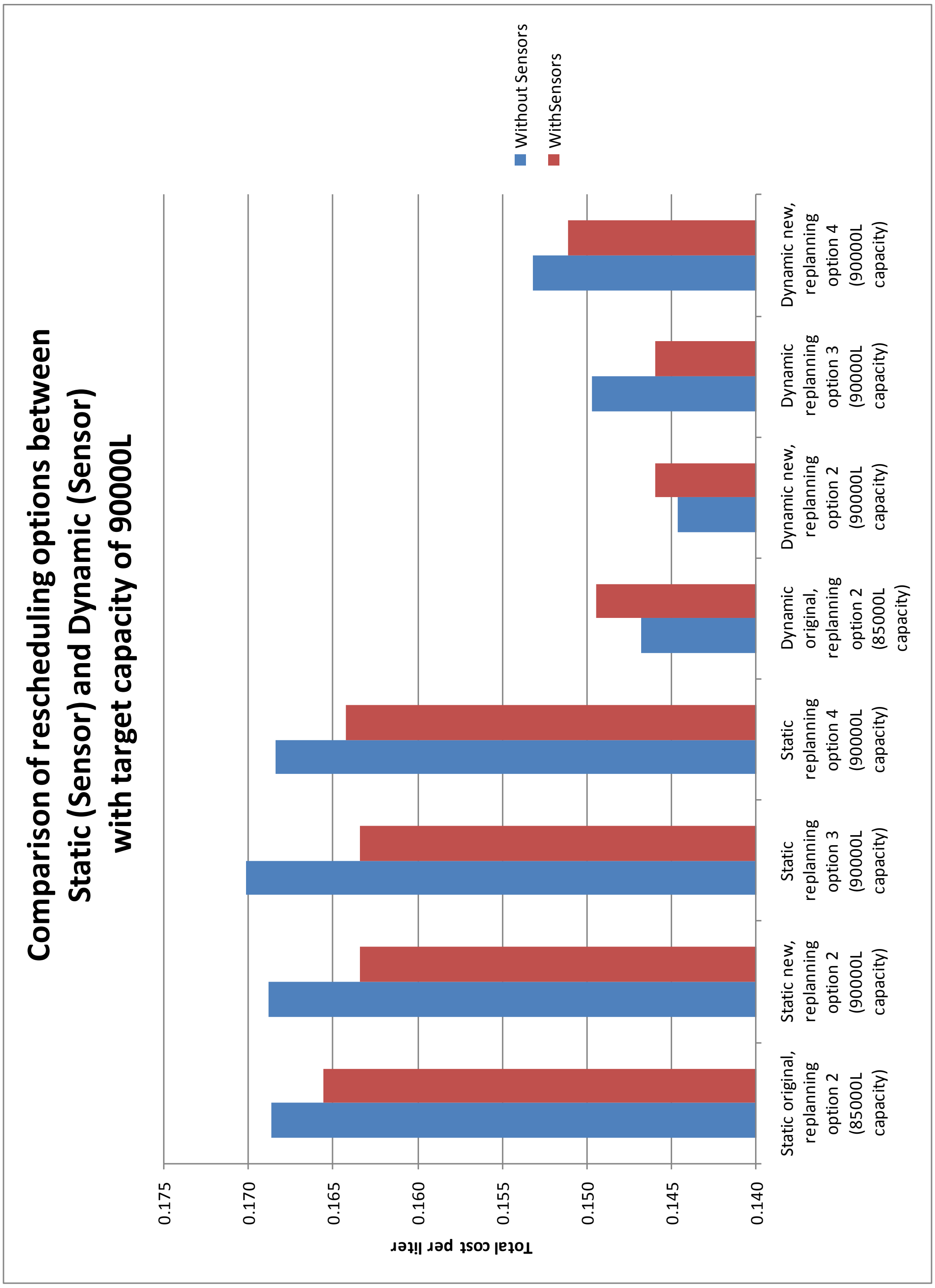
Mathematical formula for container fill rate in % (2/2)

$$\boldsymbol{Container\ fill\ rate\ in}\ \%\ (\boldsymbol{hW}, \boldsymbol{hT}, \boldsymbol{sT}, \boldsymbol{Mh}, \boldsymbol{dB}, \boldsymbol{hB}, \boldsymbol{dNoB}, \boldsymbol{dWithB})$$

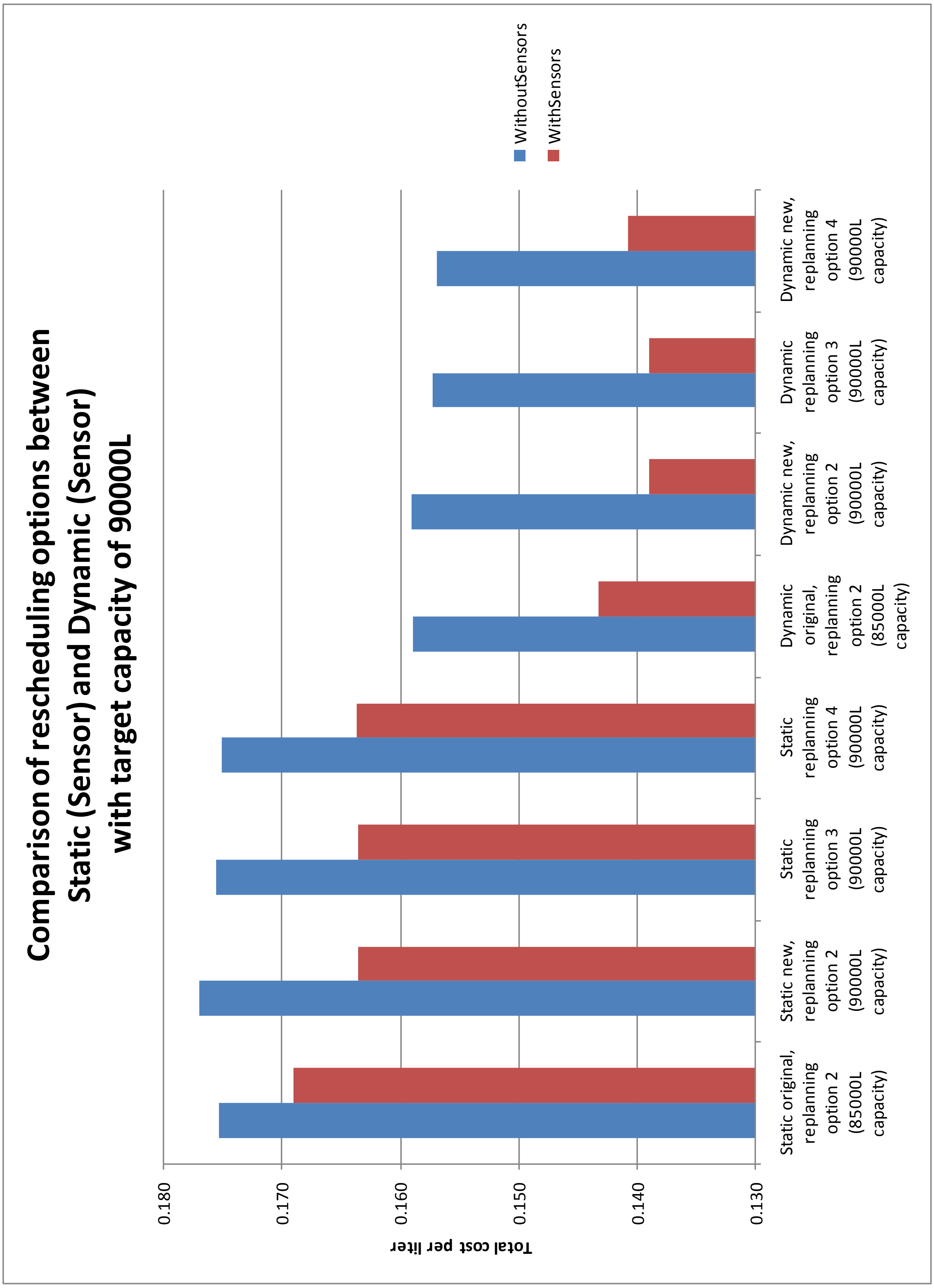
$$= \begin{cases} \boldsymbol{if}\left(\boldsymbol{hW}-\left(\frac{\boldsymbol{hT}*\boldsymbol{hW}}{\boldsymbol{Mh}}\right)\right) > hB \rightarrow 100*\left(\left(\left(\frac{1}{3}*\left(hW-\left(\frac{hT*hW}{Mh}\right)-hB\right)*\left(2*dWithB^2-2*\frac{\left(hW-\left(\frac{hT*hW}{Mh}\right)\right)}{tan\left(\frac{dB}{hB}\right)}\right)+dWithB \right.\right.\right. \\ \left. -\left(2*\left(hW-\left(\frac{hT*hW}{Mh}\right)\right)/tan\left(\frac{dB}{hB}\right)\right)^2\right)/10^6+\left(\frac{1}{3}*hB*(dNoB^2+dNoB*dWithB+dWithB^2)\right)/10^6 \\ +\left(\frac{1}{3}*\left(\frac{hT*hW}{Mh}\right)*sT^2+sT*dWithB-\left(2*\left(hW-\left(\frac{hT*hW}{Mh}\right)\right)*tan\left(\frac{dB}{hB}\right)\right)^2\right)+dWithB \\ -\left(2*\left(hW-\left(\frac{hT*hW}{Mh}\right)\right)*tan\left(\frac{dB}{hB}\right)\right)^2\Big)/10^6 \\ /\left(\left(\left(\frac{1}{3}*\left(Mh-\left(\frac{hT*Mh}{Mh}\right)\right)*\left(2*dNoB^2+2*\left(Mh-\left(\frac{hT*Mh}{Mh}\right)\right)*\tan\left(\frac{dB}{hB}\right)\right)+dNoB\right.\right.\right. \\ +\left(2*\left(Mh-\left(\frac{hT*Mh}{Mh}\right)\right)*\tan\left(\frac{dB}{hB}\right)\right)^2\Big)/10^6+\left(\frac{1}{3}*hB*(dNoB^2+dNoB*dWithB+dWithB^2)\right)/10^6 \\ +\left(\frac{1}{3}*\left(\frac{hT*Mh}{Mh}\right)*sT^2+sT*dNoB+\left(2*\left(Mh-\left(\frac{hT*Mh}{Mh}\right)\right)*\tan\left(\frac{dB}{hB}\right)\right)^2\right)+dNoB \\ \left.+\left(2*\left(Mh-\left(\frac{hT*Mh}{Mh}\right)\right)*tan\left(\frac{dB}{hB}\right)\right)^2\Big)/10^6\right) \end{cases}$$

APPENDIX 29 – REVIEW OF RESCHEDULING UNDER 90,000L TARGET CAPACITY AND SENSORS

378 containers



700 container case



Appendix 30 – Expected number of trucks w.r.t. the system size

Expected number of trucks w.r.t. the system size

Average # of emptyings per week (average fill rate of containers: 57%, based on preceeding reseach):
1,09
Possible amount of containers that can be handled by one truck (work day of 7,5h, no shifts):
55
Possible amount of containers that can be handled by one truck (work day of 13h, shifts):
95

Assumption: a container has to be emptied approx. every 1,09 weeks (current situation)

# Containers (system size)	# of working days per week	working hours per day	Expected # of containers that have to be emptied thoughout a week	Expected # of containers that have to be emptied thoughout a day	# needed trucks to cope with demand (100% balanced workload)	MAX # of trucks (incl. a daily fluctuation in demand of 20%)	MAX # of trucks (incl. a daily fluctuation in demand of 40%)	
1500	5	7,5	1378	276	6	7	8	
1500	5	13	1378	276	3	4	5	
1500	6	7,5	1378	230	5	6	6	
1500	6	13	1378	230	3	3	4	GOAL
1000	5	7,5	918	184	4	5	5	
1000	5	13	918	184	2	3	3	
1000	6	7,5	918	153	3	4	4	
1000	6	13	918	153	2	2	3	
451	5	7,5	414	83	2	2	3	CURRENT
451	5	13	414	83	1	2	1	
451	6	7,5	414	69	2	2	2	
451	6	13	414	69	1	1	2	
378	5	7,5	347	69	2	2	2	SIMULATION
378	5	14	347	69	1	1	2	
378	6	7,5	347	58	2	2	2	
378	6	13	347	58	1	1	1	

Average # of emptyings per week (average fill rate of containers: 90%):
1,91
Possible amount of containers that can be handled by one truck (work day of 7,5h, no shifts):
55
Possible amount of containers that can be handled by one truck (work day of 13h, shifts):
95

Assumption: a container has to be emptied approx. every 1,91 weeks (improved situation)

# Containers (system size)	# of working days per week	working hours per day	Expected # of containers that have to be emptied thoughout a week	Expected # of containers that have to be emptied thoughout a day	# needed trucks to cope with demand (100% balanced workload)	MAX # of trucks (incl. a daily fluctuation in demand of 20%)	MAX # of trucks (incl. a daily fluctuation in demand of 40%)	
1500	5	7,5	785	157	3	4	4	
1500	5	13	785	157	2	2	3	
1500	6	7,5	785	131	3	3	4	
1500	6	13	785	131	2	2	2	GOAL
1000	5	7,5	523	105	2	3	3	
1000	5	13	523	105	2	2	2	
1000	6	7,5	523	87	2	2	3	
1000	6	13	523	87	1	2	2	
451	5	7,5	236	47	1	2	2	CURRENT
451	5	13	236	47	1	1	1	
451	6	7,5	236	39	1	1	2	
451	6	13	236	39	1	1	1	
378	5	7,5	198	40	1	1	2	SIMULATION
378	5	14	198	40	1	1	1	
378	6	7,5	198	33	1	1	1	
378	6	13	198	33	1	1	1	

APPENDIX 31 – CONTAINER EXPERIMENT (CALCULATION OVERVIEW)

$$\bar{x} \pm z \frac{s}{\sqrt{n}}$$

Experiment with 5m^3 container model (scale 1:10,4)

(accuracy 0,5 cm, normal distribution assumed)

Experiment number	# of trash bags	altitude in centimeter (side corner point towards top, NOT shaked yet)	altitude towards top AFTER SHAKING in centimeter
1	**108**	6,0	**5,5**
2	**95**	9,0	**7,0**
3	**100**	7,0	**6,0**
4	**118**	6,5	**5,5**
5	**101**	9,0	**7,0**
6	**111**	5,0	**5,5**
7	**112**	7,5	**6,0**
8	**120**	7,0	**5,0**
9	**109**	5,5	**6,0**
10	**110**	6,5	**6,0**
11	**105**	6,0	**5,0**
12	**118**	5,5	**5,0**
13	**117**	5,5	**5,0**
14	**106**	6,0	**6,0**
15	**99**	10,0	**6,5**
16	**125**	4,5	**4,5**
17	**111**	5,5	**5,5**
18	**109**	6,0	**6,0**
19	**115**	6,5	**5,5**
20	**107**	7,5	**6,0**
Average	**109,8**	6,6	**5,725**
Sample variance S^2	55,76	1,915	0,412
√n	4,472		
C-value (Student dist.) at 95%, two sided	2,086		
C-value (Student dist.) at 90%, two sided	1,725		

95% Confidence interval for:

	lower limit	upper limit
# of trash bags:	83,8	135,8
altitude in centimeter (side corner point towards top, NOT shaked yet)	5,7	7,5
altitude towards top AFTER SHAKING in centimeter	5,5	5,9

90% Confidence interval for:

	lower limit	upper limit
# of trash bags:	88,3	131,3
altitude in centimeter (side corner point towards top, NOT shaked yet)	5,9	7,3
altitude towards top AFTER SHAKING in centimeter	5,6	5,9

Comparison with reality:

(for calculations see data sheet "volumeberekening ondergrondsecontainer NIEUW")

Real USED VOLUME in % (according to altitude after shaking)

	lower bound	upper bound
95% confidence interval for USED VOLUME of a real container	73,4%	78,4%
90% confidence interval for USED VOLUME of a real container	76,8%	78,0%

LOST VOLUME in % (according to altitude after shaking)

	lower bound	upper bound
95% confidence interval for USED VOLUME of a real container	21,6%	26,6%
90% confidence interval for USED VOLUME of a real container	22,0%	23,2%

Conclusion:

With a confidence of 95%, a minimum of about 21% (1,03 m^3) of the usable container volume (4,93 m^3) is lost due to the pyramide-like filliing process that takes place inside the 5 m^3 containers used by the Twente Milieu NV. Thus, the actual volume that can be considered for disposal storage is 3,89 m^3 (rounded: 3,9-4,0 m^3)). Moreover, the number of trash bags varies between 88,3 and 131,3 with a 90% confidence. This a variation of 43 bags to fill a container - which is rather large. These conclusions still needs to be verified by a test with a real container!

APPENDIX 32 – DETERMINATION OF THE MAXIMUM WORKLOAD PER DAY

% of Containers emptied per day (without may-go's, pure schedule)

	Monday	Tuesday	Wednesday	Thursday	Friday	# of emptied containers per week	average # containers emptied per day
Auto 1	41	39	55	72	30	237	47.4
Auto 2	0	28	41	67	0	136	27.2
total	41	67	96	139	30	373	74.6

System size (total # containers):	406
average % containers emptied per day:	18.4%

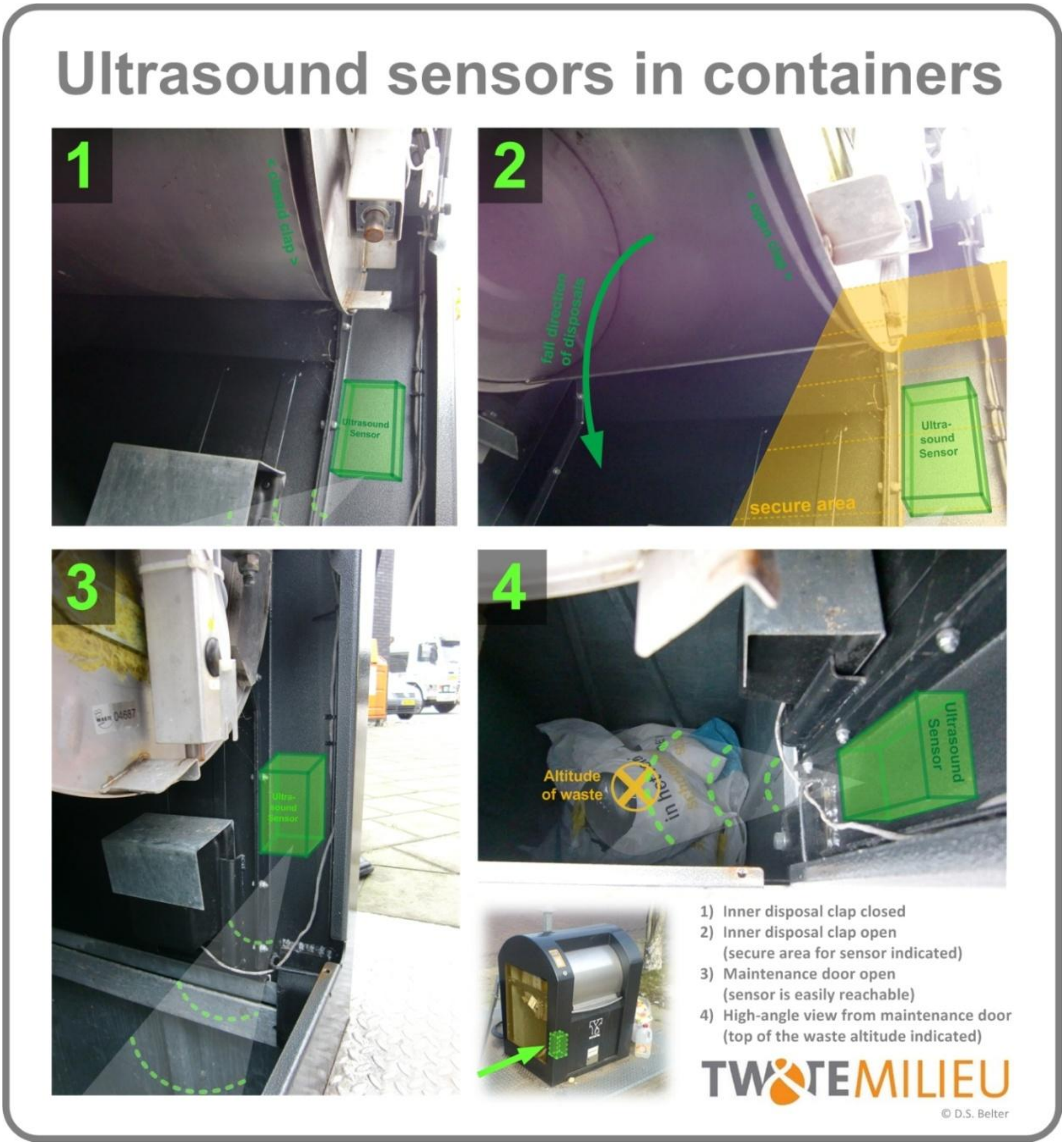
% of Containers emptied per day (with may-go's, altered schedule)

	Monday	Tuesday	Wednesday	Thursday	Friday	# of emptied containers per week	average # containers emptied per day
Auto 1	51	54	60	72	45	282	56.4
Auto 2	0	38	51	67	0	156	31.2
total	51	92	111	139	45	438	87.6

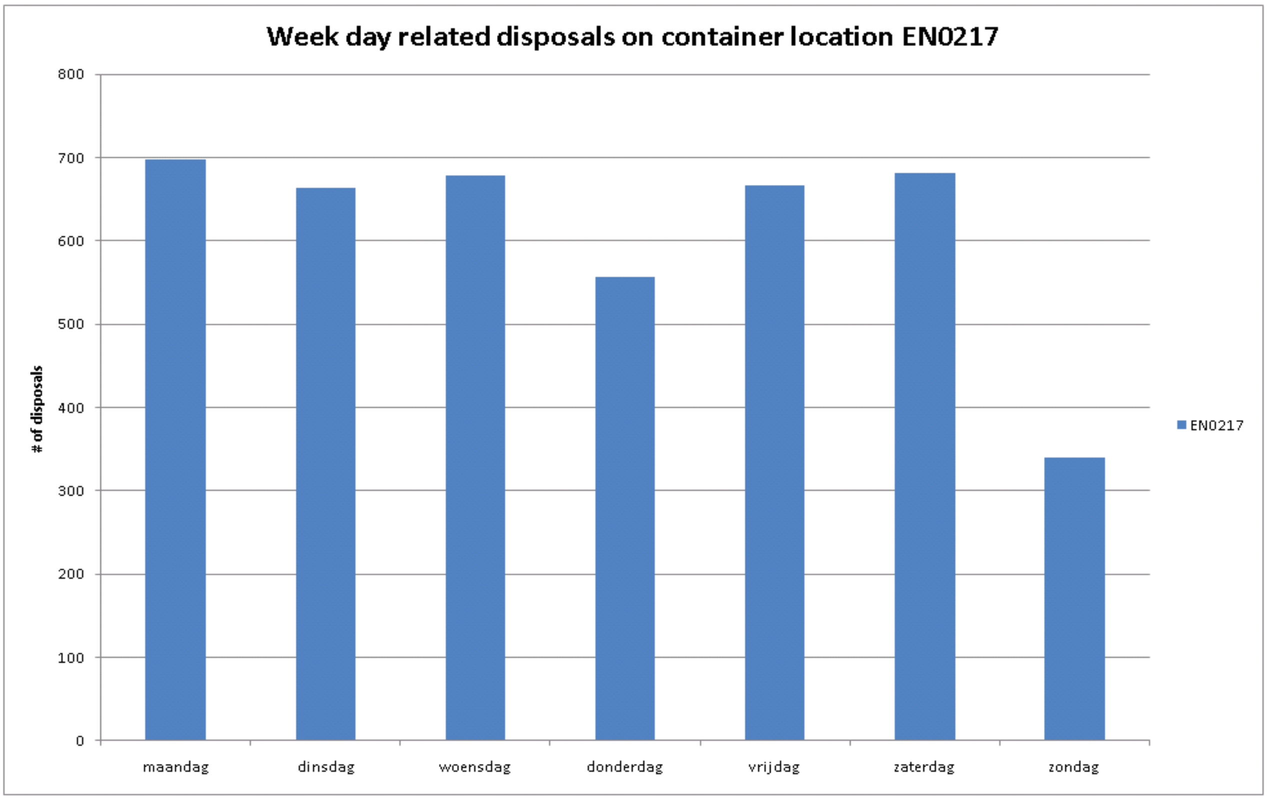
System size (total # containers):	406
average % containers emptied per day:	21.6%

# of arbitrary chosen may-go's				
ma	di	wo	do	vr
10	15	5	0	15
0	10	10	0	0

APPENDIX 33 – ULTRASOUND SENSOR INSIDE A CONTAINER



Appendix 34 – Weekday related deposits in container EN0217



APPENDIX 35
– FINANCIAL DATA RELATED TO OPERATIONS OF UNDERGROUND CONTAINERS 2010

APPENDIX 36 – HIGHER LEVEL PERFORMANCE INDICATORS USED IN THE SIMULATION STUDY

Higher level performance indicators

In addition to the KPI and the primary performance indicators also higher level indicator have been introduced to monitor the system behaviour more closely. In the simulation study executed in this research a wide variety of higher lever performance indicators have been established:

NrDeposits	NrFilled	NrEmergencies	VolPerWorktime_1 -7
NrOnTime	TimeAway	NrReplans	PercSurplus_1 - 7
NrTooLate	NrAway	Surplus	ServiceLevel_1 - 7
NrTotal	NrMustGo	AvgSurplus	AvgTfill_1 -7
VolumeEmptyings	NrMayGo	VolPerTraveltime_1 -7	NrAway_1 - 7
	NrMayGo_1 - 7	AvgCfill_1 - 7	NrMustGo_1 - 7

Most of the names of the higher level performance indicators speak for themselves; however some might need further explanation. Nr stands for number and refers to the number of containers emptied – excluding the number of deposits. TimeAway measures the amount of time that the trucks are actually on the roads, not standing still at one of the depot points. NrEmergencies describes the number of instances where the emergency planning had to be carried out, thus where the intended methodology failed and it was fallen back on a most-urgent-first algorithm. The indicators with a “1-7” at the end are constructed to measure various types of performance on a specific weekday. Hereby 1 stands for Monday, 2 for Tuesday, 3 for Wednesdays, 4 for Thursday, 5 for Friday, 6 for Saturdays and 7 for Sundays. AvgCfill is the average fill rate of the containers under a certain methodology. AvgTfill is also rather important, since in the simulation it is worked with a target value (95%) for making a collection schedule. In order to see how a method performed without slack the target fill rate should be reviewed. At last PercSurplus is the percentage that containers have been emptied too. Thus, it represents the service level of a collection method. Initially this indicator was one of the primary one, however due to the fact that it is a ratio and that different methods yield different amounts of emptying executed, it seems better to look at the absolute number of surplus emptying for further comparisons.

NOTES

Subject index