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SIMULATION-OPTIMIZATION OF WASTE COLLECTION BASED ON ULTRASONIC LEVEL MEASUREMENTS

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KEYWORDS

Simulation-optimization, waste management, ultrasonic measurements.

ABSTRACT

This paper describes a study of improving the waste collection process through real-time simulation- optimization based on ultrasonic level measurements. In the study, ultrasonic level meters are placed inside waste containers and programmed to send measurement values to a computer server via GPRS at regular intervals. The measurement values are processed in a simulation-optimization program in order to determine which waste containers to visit a specific day. The program tries to minimize the number of collections over time while at the same time find the best routes to take. The aim of this approach is to minimize the driving distance and thereby minimize CO2 emissions.

INTRODUCTION

The rate at which waste containers fill up may vary depending on factors such as, for example, season, weather, holidays, feasts, and/or salary payment. Despite variations in fill levels, waste containers are usually emptied based on a static schedule with fixed collection dates and predetermined collection routes. Two potential drawbacks of such static schedules can be identified; a) the container is not completely filled (i.e. is emptied too soon), or b) the container gets overfilled (i.e. is emptied too late). In both cases the container is emptied at the wrong point in time and the collection process is not optimal when considering work effort, driving distance, and customer service. One way to overcome these drawbacks and improve the waste collection process is to schedule the collection dynamically (e.g. daily) based on the containers' fill levels. With such dynamic scheduling it is possible to ensure that the containers are emptied at the optimal point in time.

For realizing a dynamic scheduling, it must be possible to measure the containers' fill levels continuously in an efficient way. One way to do this is to mount ultrasonic level meters on the containers, which allows convenient measurements without physical contact. In short, an ultrasonic level meter reflects ultrasonic waves off the waste inside the container and converts the time between wave transmission and echo reception into distance. Measurements can be performed both in closed and opened containers, and liquids as well as solid substances (for example, paper, glass, metal, and plastics) can be measured.

In this study, ultrasonic level measurements are included in a simulation-optimization process for improving the waste collection process. More specifically, the aim of the simulation-optimization is to reduce fuel consumption, and thereby CO2 emissions, by avoiding visiting containers that are not completely filled. While several previous studies have investigated the use of remote measurement of waste containers (see for example [1-3]), we are not aware of any previous studies of simulation-optimization based on measurement values.

In the next section, ultrasonic level meters are presented in further detail. In Section III, the simulation-optimization process is described, followed by a presentation of the scenarios used for evaluating the process in section IV. Results from the study and conclusions are presented in Section V and VI, respectively.

ULTRASONIC LEVEL METERS

General description

An ultrasonic sensor emits high frequency (20 kHz to 200 kHz) acoustic waves and converts the time between wave transmission and echo reception into distance. The sensors are

used for non-contact level measurements of everything from highly viscous liquids to bulk solids. Measurements can be performed both in closed and opened containers. The sensors are also commonly used in water management applications for pump control and flow measurement.

Since measurements are affected by changing speed of sound (due to, for example, temperature variations or turbulence), correction algorithms are applied in order to ensure an acceptable accuracy of the measurements.

Other factors affecting the precision of the measurement are turbulence, foam, steam, vapors, and changes in the concentration of the process material. Turbulence and foam hinder the acoustic wave from being properly reflected back, steam and vapors distort the wave, and fluctuations in concentration affects the amount of energy in the acoustic wave that is reflected. To prevent these factors from disturbing the sensor, stilling wells and wave guides are used.

For precise measurements, careful mounting of the sensor is required in combination with a container that is relatively free of weldments, brackets, etc. Such things may cause false returns and erroneous response, although they are in most cases possible to detect and compensate for.

Device used in study

In the study, an ultrasonic level meter called UDM-G is used (Figure 1). Measurement data from the UDM-G meter is transmitted by GPRS via a GSM modem, which allows remote and wireless monitoring of the meter. The UDM-G level is programmed to send two measurements reports per 24 hours.



Figure 1: The UDM-G ultrasonic level meter (real height is 195 mm).

The meter is mounted on the top of the container and has a measuring range of 0.05 - 3 meters. The measurement accuracy is less than 0.02 meters. The UDM-G meter can be used in various types of containers and used to measure compact, liquid, solid and transparent materials. In this study the focus is on measuring waste – including for example glass, paper, aluminum, and biological waste.

An example of measurement values from an UDM-G level meter mounted on a waste container is presented in Figure 2. As can be seen in the figure, during the selected time period the fill level of the container increases from about 30% to 80%.



Figure 2: Measurement data from waste container.

The measurement values can not only be used to monitor the historical and current fill levels, but also to forecast the quantity of the waste. Containers equipped with ultrasonic level meters transmit measurement values by GPRS via a GSM modem. Values are sampled continuously and transmitted at regular intervals with a default setting of two reports per 24 hours. The reports are received by a computer server that stores the values in a database.

SIMULATION-OPTIMIZATION PROCESS

Overall system

Data sent from the level meter are received by a computer server and used in a simulation-optimization process in order to find the most efficient waste collection routes (Figure 3).

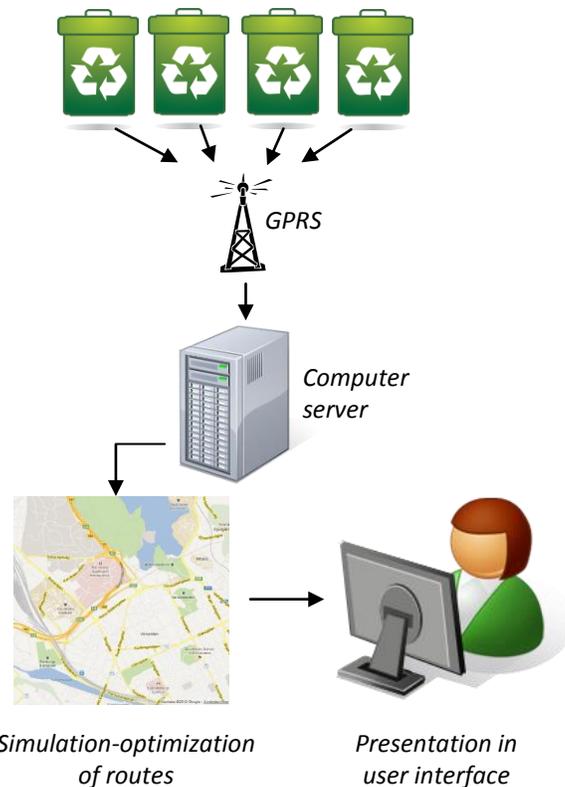


Figure 3: Overall system.

The routes resulting from the simulation-optimization process are presented to the user on a virtual map on a web page, according to Figure 4.

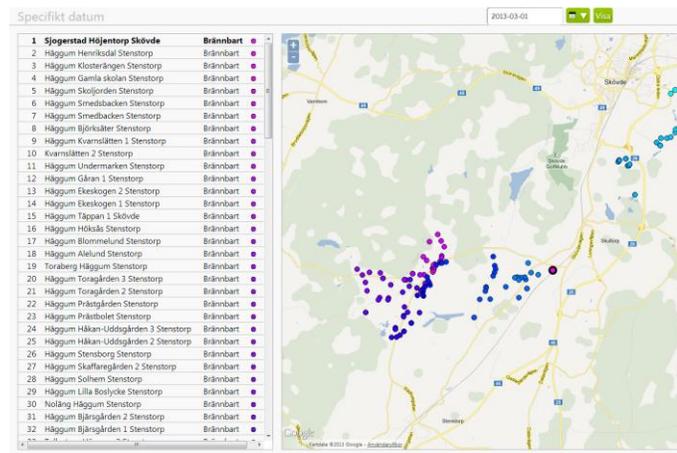


Figure 4: Containers presented on a virtual map.

Simulation

For simulating the waste collection process, a discrete-event simulation model has been constructed using the C# programming language. The reason for using the discrete-event simulation paradigm is that it provides a mean for incorporating complex relations using easier methodologies and tools compared to mathematical programming [4]. The discrete-event simulation model essentially consists of a set of system states and transitions between these states, which correspond to elements and event sequences in the real waste collection process.

When performing optimizations, the simulation is used by an optimization algorithm to evaluate the performance of the system based on given parameter values (Figure 5). So called simulation-based optimization is an iterative process; the optimization algorithm generates a set of routes, and feeds them to the simulation model, which computes CO2 emissions. Based on the evaluation feedback obtained from the simulation model, the optimization algorithm generates a new set of parameter values and the generation-evaluation process continues until a user-defined stopping criterion is satisfied. Such a criterion may, for example, be that a certain amount of time has passed, or that specific objective values have been achieved.

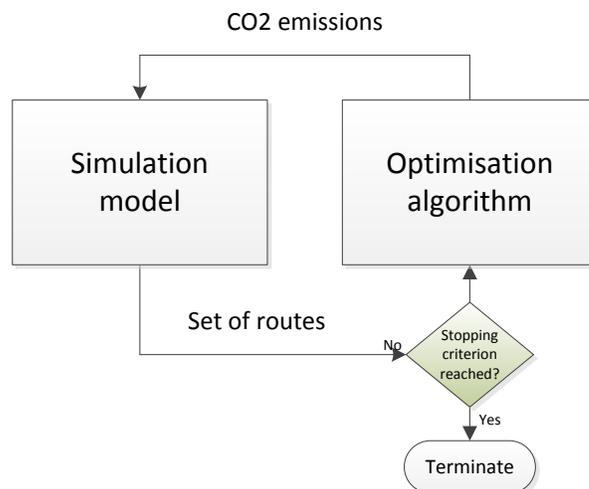


Figure 5: Simulation-optimization process.

Optimization

Finding the shortest route between a number of points (in this case represented by waste containers) might seem simple, but is classified as a "NP-hard" problem in its simplest form [5]. This means that the time it takes to solve the problem grows exponentially with the problem size (that is, the number of nodes). In a real-world routing problem, there are often a large number of parameters to consider. For example, there might be a fleet of heterogeneous vehicles with different weight, volume, and speed capacities. Furthermore, the vehicles may also have different operating costs and special working hours. When undertaking route planning, all the different parameters must be considered simultaneously.

Finding the optimal route is possible, but might take very long time because *all* possible routes must be evaluated in order to find the best one. Even for small-sized problems there are a huge number of possible routes. As an example, for a problem with only 15 nodes to visit, there are 6 227 020 800 possible routes. Due to the general complexity of routing problems, optimization techniques that are not guaranteed to find the optimal solution, but a sufficiently good one in a short time, are often used rather than exact methods. This is also the strategy selected in this study.

Genetic algorithms are a class of such inexact optimization techniques that can be used to approach routing problems [6], and this is also the technique used in this study. Genetic algorithms are essentially based on Darwin's theories about "survival of the fittest" [7]. According to this theory, in a population of individuals (solutions), the ones having the most desirable characteristics will be given the best opportunities to mate and carry on their genes. In this way, Darwin argued, good genes will propagate through generations and the population increasingly improves over time.

In evolving a population of solutions, evolutionary algorithms apply biologically inspired operations for selection, crossover and mutation. The operators are applied in a loop, and an iteration of the loop is called a generation. In the pseudo code below, the basic steps involved in this evolutionary process are presented.

```
Initialize population
Evaluate the fitness of solutions in the
population
repeat
  Select solutions to reproduce
  Form a new generation of population through
  crossover and mutation
  Evaluate the new solutions
until terminating condition
```

In this study, a solution consists of a collection of routes (a specification of which containers to visit a specific day). For the initial population, solutions are generated randomly. During each generation, a proportion of the solutions in the population is selected to breed offspring for the next generation of the population (that is, create new solutions). Solutions are selected based on their fitness, representing a quantification of their optimality, in this case the CO emissions of the route (basically a transformation of driving distance). From the solutions selected, new solutions are created to form the next generation of the population. For to creation of each new solution, two parent solutions are chosen and through crossover an offspring is produced. Occasionally, the new solution can undergo a small mutation in order to keep the diversity of the population large and avoid local minima. A mutation involves changing an arbitrary part of a solution with a certain probability, in this case changing the order of two of the collection sites to visit. When the new population is formed, the average fitness will have generally increased and after evolving populations during some time near-optimal collection of routes have been found. At the end, the route collection involving the shortest driving distance is selected. This route usually involves as few collections as possible, that is, no container is emptied before it is sufficiently filled.

EVALUATION SCENARIOS

For evaluating the applicability and the gain of the simulation-optimization process two real-world scenarios have been identified and used for evaluation. The first scenario represents a larger city in Sweden in which the waste containers are equipped with level meters. The second scenario represents a country-side city in Sweden in which level meters are currently not used, but in which the authorities are interesting in evaluating the potential of the technique. In other words, the first scenario aims to evaluate the *actual* gain of using simulation-optimization based on level measurements, while the other scenario aims to evaluate the *potential* gain. The scenarios are described in further detail below.

Scenario 1: Evaluation of actual gain

Scenario 1 includes 20 waste containers located in a densely populated city. Each of the containers is equipped with an UDM-G meter (see Section II-B) and programmed to send measurement reports twice per 24-hour period. Currently, the containers are emptied at fixed collection dates with either seven or fourteen days in between.

For building the simulation model, measurement values from the containers were first collected for three full months. The collected values clearly revealed three categories of containers with respect to fill rate, and these have been used in the simulation:

- a) containers that are more than 70% filled up at collection (in total 12),
- b) containers that are filled to approximately 65-70% at collection (in total 6), and
- c) containers that are filled to approximately 50% at collection (in total 2).

To ensure that a container is never overfilled, the optimization has been configured so that all containers are always emptied before they get filled to 85%.

Scenario 2: Evaluation of potential gain

Scenario 2 aims to evaluate the potential gain of using simulation-optimization based on level measurements in a country-side city. In the city, the waste containers are distributed over a relatively large geographical area. For the study, containers having a volume of 500 liters or more are selected. The majority of these containers are owned by companies or industries which produce relatively large amounts of waste. The current cost of the ultrasonic level meter and the belonging GSM subscription do not motivate to consider smaller containers (which are usually owned by private individuals).

For evaluating the scenario, the simulation model was configured to reflect the settings of the city and the included containers. To mimic level meters in the simulation, predicted filling rates of each container were used as specified by experienced staff members of the waste collection organization.

The next section continues with presenting the results from the scenarios.

RESULTS

In Scenario 1 (actual gain), the results show that in total 85 collections can be saved per year without risking any container to be overfilled. To empty a container usually takes 5-15 minutes, so in average approximately $0.6 \times 86 \approx 56$ work hours can be saved. With respect to driving distance, only a few kilometers can be saved each year. The reason for this is

the geographical location of the containers; the containers are located in clusters with only a few hundred meters in between. An example of one cluster, include half of all containers, are given in Figure 6. When the containers are located this way, avoiding collecting one or a few containers does not affect the driving distance since the location has to be visited any way.

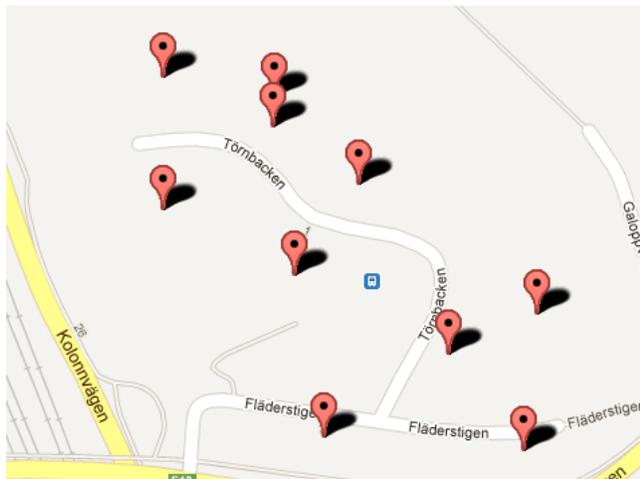


Figure 6. Example of container cluster in real-world scenario.

In Scenario 2 (potential gain), comparative simulation-optimizations with and without level measurements were performed in order to estimate the gain of using level meters. The results show that a 5-35% reduction of CO₂ emissions, as well as working effort, can be achieved when using ultrasonic level meters in the waste collection process. It is clear from the results that the largest gain of level meters is achieved for collection routes at the country side, where the distance between containers is relatively large.

SUMMARY AND CONCLUSIONS

Today, waste collection is usually performed according to static schedules although the rate at which waste containers fill up may vary depending over the year depending on season, weather, holidays, feasts, salary payment, etc. A consequence of static schedules is that the container is seldom emptied at the exact right day – it might either be emptied when it is not yet full, or when it is overfull. When either of this happens, the collection process is not optimal.

In this study, we investigate the possible gains of schedule waste collections dynamically (e.g. daily) instead of statically by equipping the containers with ultrasonic level meters and utilizing simulation-optimization. The level meters are placed inside the waste containers and programmed to send measurement values to a computer server via GPRS. The measurement values are processed in a simulation-optimization program in order to determine which waste containers to visit a specific day. The program tries to

minimize the number of collections over time while at the same time find the best route to take. The aim of this approach is to minimize the driving distance and thereby minimize CO₂ emissions.

In evaluating the simulation-optimization, two real-world scenarios are being used. The first scenario covers a larger city in Sweden in which the containers are equipped with level meters. In this scenario, the results show no significant savings with respect to CO₂ emissions. An analysis show that this is due to the geographical location of the containers; the containers are located in clusters and avoiding collecting one or a few containers inside a cluster virtually does not affect the driving distance.

The second scenario used in the evaluation represents a country-side city in Sweden in which the containers are currently not equipped with level meters. Results from this scenario show that a quite significant (5-35%) reduction of CO₂ emissions can be achieved when using level meters compared to when not using level meters.

In general, the results indicate that the largest gain of simulation-optimization based on level measurements is achieved at the country side where the distance between containers is relatively large. In these settings, the most significant reduction of CO₂ emissions can be noticed, and also the best “pay-off” when considering the cost of the level meters in relation to the economic savings (including mainly labor costs and fuel costs).

Regarding installation costs, it is important to be aware of the relatively large investment related to purchasing and mounting ultrasonic level meters. Widespread use of level meters in the waste collection process is probably realistic first at a point where the cost of the sensors is reduced. Studies on how to produce cheaper, yet robust, sensors for the purpose are therefore needed.

Robustness is a feature that is of great importance for the sensor readings to be useful. Measurement values that are stable and reliable over time are critical for an efficient simulation-optimization process. A general and effective algorithm for eliminating noisy measurement values inside waste containers is therefore also an interesting topic for future studies and also an aspect that would improve the gain of the simulation-optimization.

In this study, a genetic algorithm was used to optimize the collection process. Another approach that should be evaluated in the future is a rule-based system using a combination of due dates and filling percentage to determine collection routes. Whenever the truck is unloaded at the garbage dump, the system could check which containers that are close in due date, and combine this information with filling percentages and distances in order to determine the next containers to visit. With this approach, even better results may be obtained.

In the future it would also be interesting to study more complex scenarios with a mix of containers that are equipped with level meters and those that are not (in this study it was assumed that all containers included in the simulation were equipped with level meters). It would also be interesting to study what happens if measurements reports are from the level meters are sent only once per 24 hours (instead of twice) for energy saving reasons.

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BIOGRAPHY

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