Towards a Dynamic Waste Collection Management System using Real-time and Forecasted Data

George Asimakopoulos,
Sotiris Christodoulou, Andreas Gizas,
Vassilios Triantafillou,
Giannis Tzimas, Emmanouil Viennas
Computer & Inform. Engineering Dept.
Technical Educational Inst. of Western Greece
Antirion, Greece
{gasimakop@gmail.com, sxristod@teimes.gr, gizas@ceid.upatras.gr, triantaf@teimes.gr, tzimas@cti.gr, viennas@gmail.com}

John Gialelis, Dimitris Karadimas,
Andreas Papalambrou
Industrial Systems Institute, "Athena" RIC in ICT and Knowledge Technologies, Patras Science Park, Stadiou Str.,Platani, PATRAS, Greece, GR-26504
{gialelis@isi.gr, karadimas@isi.gr, papalambrou@isi.gr}

ABSTRACT
Dynacargo, a research project under implementation, aims to change supply chain management, as the hauled goods are at the center of attention instead of vehicles, as in traditional management approaches. At the same time Dynacargo manages both delivery and collection cycles. Dynacargo aims at developing a near real-time monitoring system that monitors and transmits waste bins' fill level, which is used to dynamically manage the waste collection process by introducing distance minimization, relying on efficient routing algorithms. This paper deals with research issues that have emerged along with developments regarding specific architectural modules. In general, Dynacargo places a set of durable, low cost sensors and RFID tags on waste bins. These tags store the fill-level estimated by the sensors, which is passed through diverse communication channels and ends to a central cargo information management system. Along with this real time data harvesting, data mining techniques are utilized on historical data collected prior to Dynagargo implementation, in order to predict future waste bins fill rates. Mobile and web applications are developed in order to harvest relevant data from citizens.

Categories and Subject Descriptors
C.0 GENERAL: System architectures, **H.2.8 Database Applications:** Data Mining, **G.2.2 Graph Theory:** Graph algorithms

General Terms
Algorithms, Design, Experimentation.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from Permissions@acm.org.
16th EANN workshops, September 25 - 28, 2015, Rhodes Island, Greece
© 2015 ACM. ISBN 978-1-4503-3580-5/15/09…$15.00
DOI: http://dx.doi.org/10.1145/2797143.2797154

Keywords
Urban solid waste collection; intelligent transportation systems; data mining; graph routing algorithms.

1. INTRODUCTION
Nafpaktia municipality is a typical case of solid waste management throughout Hellas, as waste collection is based on standard time intervals and according to fixed vehicle routes. Decision making is solely empirical, which leads to biased decisions that do not take into account real needs based on data.

This has led to results far from optimal; as it is not uncommon to have overfilled waste bins were uncollected for some days, while at the same time other unfilled bins were collected, resulting to an unsatisfied local society along with increased cost. Regarding Athens[8], it has been estimated that the 60% to 80% of the total cost of waste collection, transportation and disposal is spent during collection. The main cost reduction efforts should deal with distance and duration minimization of vehicle routes [6]. Johansson [7] proved that if the fill level of bins was taken into account and waste collection adapts accordingly, it could reduce the cost of waste collection up to 20%. Under the light of these findings, Dynacargo (Dynamic Cargo Routing on-the-Go) attempts to build a near real-time monitoring system that monitors and transmits waste bins' fill level, in order to make waste collection more efficient by cost reduction which is accomplished by minimizing distances covered by refuse vehicles.

2. RELATED WORK & INNOVATION OF DYNACARGO
There are various approaches available in order to harvest data from points of waste collection [2,3,4, 5,7,9,10]. Although they introduce interesting approaches, they cannot be used as-is in Dynacargo. This is because they introduce major costs, they do not meet Dynacargo functional requirements and are mostly customized for recyclable waste which can be managed with longer collection cycles compared to domestic waste.

This implies that Dynacargo, despite aiming at waste collection automation as existing approaches do, displays major differentiations against these approaches. At the heart of these differentiations lies Dynacargo architecture which originates from a generic multipurpose cargo-based dynamic vehicle routing approach which copes with cargo changes and collection from disperse points of concentration.

Dynacargo moves forward from sole data collection from waste concentration points, as it utilizes such data in real time in order to optimize vehicle routes during the waste collection process execution.

Another point at which Dynacargo differentiates from existing approaches is the utilization of a diverse set of data transmission techniques that is incorporated to establish data transmission from points of collection to the system in near real time. Besides GSM which induces fixed telecom costs, Delay-Tolerant Networking concepts are adapted for data transmission from the disperse concentration points to the central information system. Dynacargo DTN is based on a set of existing public commuters that are utilized as data hosts that carry data as they execute unaltered standard procedures.

3. NAFPAKTIA AS CASE STUDY

Dynacargo functional requirements evolved from the analysis of the solid waste collection and management system of Municipality of Nafpaktia, Greece, which expands in an area of 870,38 km^2 and displays a population of 27.800 citizens. Nafpaktia displays geographic and demographic aspects that sum to an ideal pilot environment for Dynacargo. It is composed from a coastal city with narrow busy streets in the historic center, coastal towns and villages with population varying following tourist seasonality, along with remote villages (up to 120 km. away) with a few dozen residents located in mountainous areas. Telecom network coverage along with public transportation frequency display significant diversion between different Municipality areas. Another diversion is that Nafpaktia displays waste transshipment from small to big refuse vehicles. Requirement analysis initiated with an as-is analysis in order to formally document the current waste management process. Several indicative waste collecting routes were selected and modeled on Google Earth (Figure 1), after an assessment of peculiarities each route presents. The analysis included available waste collection historical data and information regarding related processes.

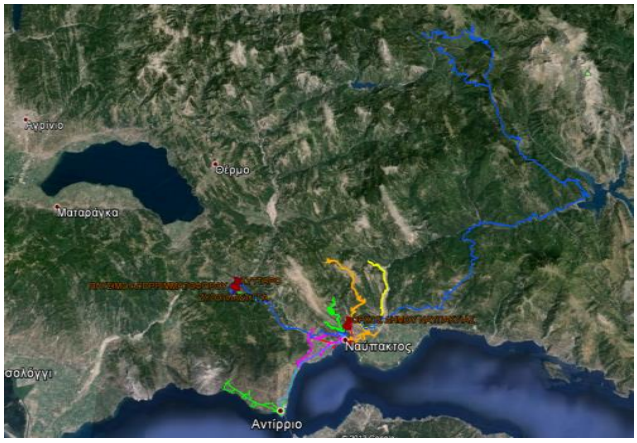

Figure 1. Indicative waste collection routes for Nafpaktia.

4. USERS & USE-CASE MODELS

Dynacargo identifies a set of target user groups which include waste collection related municipal services, system administrators, truck drivers, bins' data collectors and individual citizens.

In order to reassure the accurate Dynacargo waste level predictions, waste bin fill level data is acquired at short time intervals from as many as possible waste collection points. Data collection is realized through diverse data harvesting tools take advantage of existing transportation systems such as public bus services, postal office vehicles, taxis, municipal police vehicles, along with active social entities as these vehicles traverse the area of interest in an irregular but frequent manner. The Data Collector role can be served by either a vehicle driver (e.g., bus, taxi, postman car, etc.) equipped with the Dynacargo equipment, or anyone else who may be involved in data collection (e.g., postmen) who may use any means of transportation such a car, a bike, or by foot. Citizens improve data harvesting by reporting fill-level with a mobile application, reporting estimations of produced waste volume on unforeseen events and by checking online the bin fill levels near their residence so as to discard their waste on nearby unfilled bins.

Based on users' functional requirements, several application scenarios have been set out, which fall into two categories based on time of implementation: *Full-scale Application Scenarios* and *Pilot Scenarios* (scenarios that will be demonstrated during the project). Full-scale scenarios define use-case models for each subsystem, including the vast majority of functional requirements along with several non-functional requirements. Six major use-case models were set out modeling different usage cases of the system: Bins' Data Collector, Refuse Truck, Central System, Optimal Routes Calculation, Citizen's SmartPhone App and Citizen's Information Portal. These use cases and more detailed description of the functional requirements of Dynacargo, are described in a previous research work [1].

5. ARCHITECTURE

Functional requirements and use case models led to the definition and design of the major Dynacargo structural components, followed by decomposition to subsystems and smaller functional units. Operations, roles and significant logical relationships with other subsystems were defined for each subsystem.

Dynacargo specifications were derived based on exhausting analysis of the waste collecting process as it is performed by Nafpaktia municipality. However, Dynacargo architecture is designed as a generic cargo-based routing system along with the inherited adaptability to any other municipality regardless of specific waste collecting process characteristics. The Dynacargo architecture is presented in figure 2 and in more detail in [1]. Following, we shortly describe its main subsystems and architectural parts.

Bin Subsystem: Sensors estimate waste bin fill level and collect, store, and transmit relevant data.

Bins Data Gathering and Dispatching Unit: This unit communicates through a short range network with the Bin Subsystem and routes the collected information to the Central System, through a long range network. It can be installed at passing vehicles and is built of three components:

- *"Reader"*, which refers to the communication interface with the bin subsystem.
- *"Storage space"* which temporarily stores the data until transferred to the Central System.
- *"Data transmission"* to the Central System, through Delay Tolerant Networking (DTN) technology.

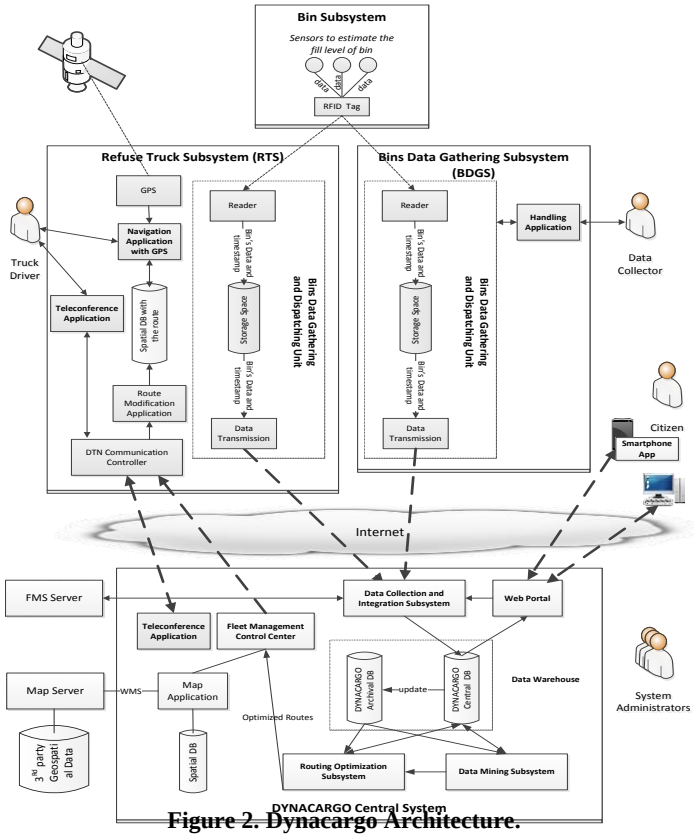

Figure 2. Dynacargo Architecture.

Bins Data Gathering Subsystem (BDGS): The BDGS is the subsystem carried by the Data Collector. It consists of the Bins Data Gathering and Dispatching Unit, combined with a very simple application for handling it. The BDGS should be portable and able to work with a battery.

Refuse Truck Subsystem (RTS): This subsystem will be installed on each refuse truck. The main part of the RTS is the Bins Data Gathering and Dispatching Unit. Additionally the RTS will be equipped with a GPS unit and a camera and will incorporate the appropriate software to provide the following functionalities:

- *GPS Navigation Application:* It is a classical navigation application through GPS, which will provide navigation guidance to the truck driver, and instructions about which bins should be collected.
- *Teleconference Application:* Teleconference communication of driver with the Central System, especially for reporting emergency situations.

The RTS will be powered by the refuse truck. The **communication** with the Central System will be based on DTN technology, which will transparently select the most suitable communication method, considering criteria like cost or speed.

Citizen Application: An application for mobile devices (smartphone, tablet), through which the citizen can choose any bin and report data for it (fill level, photo, comment, etc.).

Central System: It is the back-end system of Dynacargo. Its main part is the Data Warehouse storing all historic data, bins' data, vehicles' data and everything needed for calculating the best routes based on the current load of bins and some restrictions (Bin Collection Settings) specified by the system administrators. Moreover, Data Warehouse will store any information derived from the other subsystems, particularly from the Data Mining Subsystem and the Routing Optimization Subsystem.

Apart the above databases, the Central System will include:

Fleet Management Control Center: receives the optimized routes from the Routing Optimization Subsystem, two hours before the start of the routes and on the fly (if the routes have to be modified), and forwards them to the appropriate RTS. All spatial information for the corresponding route will be stored locally in a Spatial RTS Database. The Fleet Management Control Center can send route modifications to any refuse truck, informing properly the Navigation Application, if such need arises and provided that the refuse truck has network coverage.

The Map Application: A cartographic JavaScript API that will provide all the required functionality for creating rich-web applications based on geographic and descriptive data.

Data Collection and Integration Subsystem: This subsystem will collect bins data from the RTS, the BDGS and citizens' applications, and integrate them into the central DBs. Furthermore, it will be able to integrate data from other sources, if needed, like an independent FMS server that can operate in parallel with the Dynacargo system. The architecture design of Dynacargo does not require the existence of a classical FMS.

Data Mining Subsystem: Mainly used to estimate fullness of bins when we do not have the available information updated or is not fairly recent. It generally seeks to apply fusion techniques from multiple sources to produce more semantically rich data, thereby obtaining information on a higher level of abstraction.

Routing Optimization Subsystem: The role of this subsystem is the dynamic route planning before the starting of truck routes, and the on-the-fly modification of routes, either due to exceptional events (accident), or if the new data collected during the routes impose such changes. The routes will be calculated two hours ahead, taking into account various data that will exist in the central data warehouse system.

Citizens Web Portal: A web site, through which citizens can be informed about the current completeness of bins or report bins' data (fill level, photography, etc.) in the Central System, by selecting a bin on a map. The purpose of the Citizen Web Portal and the smartphone app are to motivate people to participate in sustainable waste management.

In the three following sections we further discuss the current design and implementation issues of three important subsystems.

6. BIN SUBSYSTEM AND FILL LEVEL ESTIMATION

The fill level estimation of urban solid waste bins appears to be a challenging a task. The irregular shape and the variety of the materials require versatile sensing approaches. The harsh environmental conditions (e.g., humidity, temperature, and dust) can significantly affect the sensor measurement accuracy and reliability.

6.1 The Physical bin system

The proposed smart waste-bin system is envisaged to be mounted on the top lid of a waste-bin and it consists of the sensing units, an

active RFID tag for data aggregation and transmission, as well as a protective enclosure for the sensors and the RFID tag that may optionally include an external battery source. On the other side, the waste-bin system interacts with an active RFID reader which could be optionally accompanied by a bare-bone-pc, i.e. a Raspberry Pi for enhanced capabilities. The aforementioned modules are described in the following paragraphs starting from the waste-bin which constitutes the main physical component and moving towards the receiver side.

6.1.1 Mobile Garbage Bin

The physical system is based on the standard type of a mobile garbage bin (MGB), also known as a "wheelie bin", used in the municipality of Nafpaktia, Greece, where the pilot of the Dynacargo project will take place. The bin has a main compartment whose internal dimensions are approximately 110x90x90 cm, consisting of slight curved-shaped walls. It has a lid-opening mechanism and is made of durable hard plastic. The lid of the bin was chosen as the point of placement of the sensors because the main compartment is subject to harsher conditions due to the presence of the waste as well as the washing procedure of the bins.

6.1.2 Sensing Unit

A comparison of various solutions including infrared proximity sensors, optical sensors and ultrasonic sensors indicated that ultrasonic sensors are the most suitable solution for the purpose of the presented architecture taking into account the harsh environmental conditions (e.g., humidity, temperature, and dust) that can significantly affect the sensor measurement accuracy and reliability. The ultrasonic sensors are advantageous in providing ranging measurements independently of the contained objects, thus making possible the corresponding translation into fill level measurements. For the purpose of this task, the ultrasonic sensors of Maxbotix were selected which provide a variety of detection patterns, accuracy and durability. Since the resolution of the ultrasonic sensors is only a few centimeters (about an inch), the selected solution can offer fine-grained accuracy for the purpose of the application. The ultrasonic sensors should be mounted in the bin lid, exposing only a small part of the sensor body. Since the sensors will operate unattended in the field, low power consumption models that also offer IP-67 protection rating can be used. An analog output is provided for the transmission of the measurements. The experimental placement of sensors on the top of the bin can be found in Figure 3.

Figure 3. Experiment setup for verification.

The measurements of the sensors essentially provide the distance to the nearest object of efficient size. Since waste in the form of irregular-shaped objects can occupy the bin space in various arrangements, there is typically some difference between the highest bin level and the actual fill percentage. Following experimentation with placement and number of sensors it was concluded that a single sensor placed in the center of the lid was providing good results but over-estimating the fill level due to the typically higher level of waste in the center of the bin. As a result, various combinations of two sensors were examined. It was concluded that the optimal results were provided by placement of two sensors in a way that their areas of detection would not overlap.

6.1.3 Active RFID Tag

Active RFID tags have been selected as the data aggregation and transmission unit for the bin subsystem. The selected tags (ZT-50-mini Tag by TagSense) can operate with standard 3V voltage input providing long lifetime that equals to millions of beacon transmissions. The employed active tags offer extra I/O pins for communicating with external devices, in our case the ultrasonic sensing units. This setup allows powering the sensors and the RFID tag from the same source, either tag's battery or an external power source.

In the Dynacargo scenarios the tag wakes up at predefined times of the day, depending on the location of the waste bin installation and on the desired measurement frequency defined by the Municipality operators.

The Dynacargo operation does not assume availability of a fixed network infrastructure that reaches all the installed bins, especially those at distant villages. Moreover, at an urban scale of operation, this is a quite realistic assumption, since thousands of sensors are sparsely deployed in a complex city and suburban terrain.

6.2 Fill Level Estimation

6.2.1 Computer model of the system

The waste-bin model that was developed is based on the use of a three dimensional matrix representing the entire waste-bin's internal volume. This model was developed using MATLAB because it offers powerful matrix handling tools. The ultrasonic sensors were also modeled as three dimensional matrices. These matrices were of the same size as the bin matrix with zero values for the areas of the bin which fall outside the detection range of the sensor and with unit values for the areas inside the detection area. One of the most crucial parameter for the simulation was waste modelling, mostly concerning its generation. The representation of waste was made using the bin matrix by setting 1 in the elementary volumes where waste was present and 0 otherwise. More challenging was the method to generate waste in a way that would be equivalent to the waste of a real bin. In absence of an existing model in the bibliography concerning how waste of irregular shape and size gradually fills a bin, it was chosen to perform extensive random scenarios of bin filling that would cover all possible combinations. Then, the less likely situations can be filtered out by statistical analysis of the derived combinations.

6.2.2 Simulation

The bin system simulation in MATLAB took place via the following steps: i) Parameters are set (sensors types, bin sizes etc.); ii) The matrices of the bin and the sensors are created; iii) Waste is generated through a random process based on input parameters; iv) The waste surface is calculated; v) The sensor values are calculated based on the smallest distance between the sensor and the waste surface; vi) The waste volume is calculated; vii) The fill percentage is calculated; and finally viii) A 3D plot of

the waste inside the bin is created. The results of interest for the purposes of this work are the actual fill percentage and the sensor measurements. Figure 4 depicts the simulated end results for a 30k-run simulation and an elementary base-edge length of 20cm for the area of responsibility of a single sensor. In this figure, the vertical axis represents the actual fill-level percentage of the area calculated each time based on the waste-bin and the sensor models, while horizontal axis represents the actual value based on the sensor model. It is noticeable that selecting other values for the elementary base-edge length did not alter the shape of the scattered points, but only the amount of spreading of the scatters for medium to low sensor values. This is expected taking into account the actual physical problem.

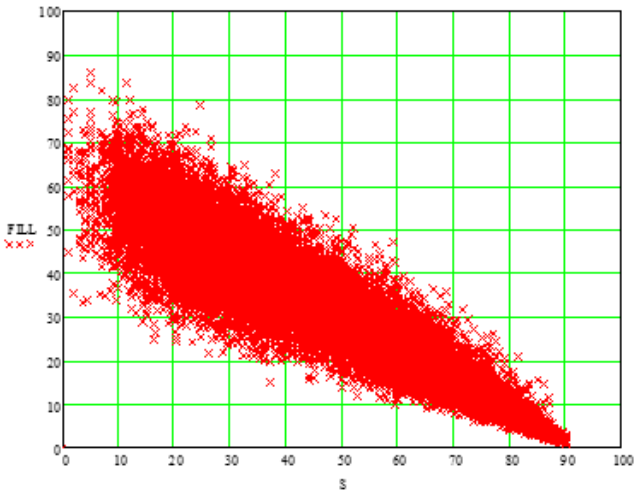

Figure 4. Simulated end results for a 30k-run simulation and an elementary base-edge length of 20cm for the area of responsibility of a single sensor

The raw results derived from a sufficient number of simulations for a variety of models' parameters selection can be further statistically processed. The selected totally random method for filling a bin followed in the simulations provided different fill-levels for a range of identical sensor values. These fill-levels have been grouped so as to extract the corresponding mean value and deviation for each group, thus treat the bin filling with elementary wastes as a Gaussian process.

7. BINS' DATA GATHERING AND DISPATCHING UNIT

The Bins' Data Gathering and Dispatching Unit (or simply Collector Unit) consists of an active RFID reader and a small-form-factor computer (currently a Raspberry Pi), consuming about 10 W of power (maximum) and having two USB 2.0 ports, built-in WiFi and Bluetooth, and one Ethernet port that is supported by GNU/Linux operating system running from a microSD card. The selected active RFID reader (ZR-USB RFID Reader by TagSence) is inherently designed to communicate with the TagSense ZT-50 active tag. The ZR-USB active reader communicates with the active tags using a variable packet length protocol which is designed to conserve power on the tag. The air interface protocol layer is based on the underlying IEEE 802.15.4 industry standard, which is best-known as the physical layer for Zigbee.

The waste bins are equipped with the Field Unit and the active RFID tags transmit periodically their identity and a sensed value regarding bin's fill level. This option allows the minimal possible information to be transmitted periodically. All tags are configured to operate in beacon mode, broadcasting the information every few seconds in a range of about 100 meters. Active RFID tag transmission technology is much lighter in complexity and in coping with harsh environments compared to that of WSNs making the architecture robust and resistant.

The Collector Unit could be held by any approved personnel or installed in a vehicle of existing organized transportation systems such as public bus services, postal office vehicles, taxis, municipal police vehicles, etc. in order to unobtrusively collect the required information. As the vehicle roams around the city, the RFID reader reads the tags and collects and stores the information to the storage area. Given the short "packet" size (less than 128 bits), the tag range (100 meters), and a realistic average speed of 40 km/h in a city, the tag beacon interval is extracted so as the passing vehicle is able to complete all necessary transactions with the smart-bin. The use of RFID technology allows reading multiple tags simultaneously (group of nearby bins), without collisions and re-transmissions, as it would be the case of a wireless sensor network.

In order to cope with increased telecommunication costs and infrastructure upgrades, the Collector Unit defers transmissions to the Central System until an Internet connection becomes available. The Delay Tolerant Networking paradigm ensures that the information is retained in the bins, until a Collector Unit passes nearby and then in the Collector Units, until an Internet connection is available.

8. DATA MINING & PREDICTION ANALYSIS SUBSYSTEM

The data mining and prediction analysis subsystem is based on the data warehouse infrastructure, from which the data are extracted, so that the various data mining scenarios can be realized. The data mining process can be quite challenging and time consuming since the efficient parametrization of the chosen variables requires experience on behalf of the scientists and is mostly empirical. The research team tried to execute different scenarios in order to analyze the behavior of existing data mining methods on this dataset and to investigate the existence of association rules and possibly to make interesting conclusions.

8.1 Data mining algorithms study

Below we present the process that was followed in order to study and adjust the data mining algorithms within the scope of the project, as well as the visualization of the results. The whole subsystem is realized in a Microsoft SQL Server RDBMS, utilizing the relevant Analysis Server (Microsoft Analysis Services), where a Mining project has been created in the supported programming environment, linking the central database with the Analysis Server.

At the first stage, a data mining structure was constructed based on a single table, merging the data from the various RDBMS tables. While creating the data mining structure, the variables that took part in the analysis process where chosen. Furthermore, each variable type was carefully defined in order to be effectively handled by the data mining algorithm. For example, some variables are continuous such as dates, some are distinct and some

must be discretized for the sake of the analysis at specific intervals. Also, one of the variables was defined as the key in order to ensure distinctness between different records.

In the scope of the subsystem a clustering model was defined, as well as variations of it with different parameters, aiming to reveal the general distribution range of variables in the entire range of data. From the different clusters we got from the analysis, we tried to define which variable(s) have a distinct role and can serve as representatives and whether it makes sense to separate the data into clusters.

In parallel with the above, a study was performed using other data mining tools, because not all methods were fully covered by the selected configuration. The same data were imported in WEKA which provides a richer set of data mining methods, and also additional algorithms to some of the methods. Using this configuration, we tried to find a combination of variables that could link the data and provide some insight. Also, a classification process took place according to the distance between the waste bins and we investigated how this affects the total cost.

8.2 Results visualization

Besides the above, using the Analysis Server, we constructed a cube in order to visualize the data. The cube has as many dimensions (columns) as the data we want to use. Queries on these data are performed utilizing the PivotViewer control, a Silverlight web browser plug-in. We made use of PivotViewer in order to implement the main interface for user queries. The choice was made based on the fact that PivotViewer leverages Deep Zoom which is the fastest, smoothest, zooming technology on the Web. As a result, it displays full, high resolution content without long loading times. Moreover, the animations and natural transitions provide context in a user-friendly way and prevent users from feeling overwhelmed by large quantities of information. PivotViewer enables users to interact with thousands of objects at once while sorting and browsing data, making it possible to track trends easily and find the information they are looking for. In PivotViewer, the user can apply filters on variables based on the respective variable range. Filters can also be applied simultaneously to many variables. Apart from filtering, the data can be sorted based on any variable without using filters. For example, to show the fullness of the waste bins for a specific week of a month in some specific time range, the appropriate filters can be selected and sort the data by date.

In figure 5, we present a small sample of results for the experiments we conducted. The model that was chosen made use of association rules. The concept was to predict the weight percentage of the waste bins based on the day, month and region where the waste bin is located, as well as the respective weight percentage of the waste bin that were given as input.

Probability	Importance	Rule
0.301	0.066	Dd = 18 -> Weight = 53 - 66
0.287	0.045	Dd = 5 -> Weight = 53 - 66
0.287	0.045	Dd = 5, Offday = 0 -> Weight = 53 - 66
0.283	0.053	Dd = 30 -> Weight = 66 - 81
0.277	0.029	Dd = 19 -> Weight = 53 - 66
0.275	0.027	Dd = 7, Offday = 0 -> Weight = 53 - 66
0.275	0.027	Dd = 7 -> Weight = 53 - 66
0.275	0.026	Dd = 19, Offday = 0 -> Weight = 53 - 66
0.275	0.026	Mm = 5 -> Weight = 53 - 66
0.274	0.025	Dd = 9 -> Weight = 53 - 66
0.274	0.025	Dd = 9, Offday = 0 -> Weight = 53 - 66
0.273	0.024	Dd = 15 -> Weight = 53 - 66
0.272	0.022	Region = Region4, Offday = 0 -> Weight = 53 - 66
0.272	0.022	Region = Region3, Offday = 0 -> Weight = 53 - 66
0.272	0.021	Offday = 1, Region = Region8 -> Weight = 53 - 66
0.271	0.020	Region = Region4 -> Weight = 53 - 66
0.271	0.021	Mm = 5, Offday = 0 -> Weight = 53 - 66
0.271	0.020	Mm = 3 -> Weight = 53 - 66
0.271	0.033	Dd = 9 -> Weight = 66 - 81
0.271	0.033	Dd = 9, Offday = 0 -> Weight = 66 - 81
0.270	0.033	Region = Region7 -> Weight = 66 - 81
0.270	0.017	Dd = 6, Offday = 0 -> Weight = 53 - 66
0.270	0.017	Dd = 6 -> Weight = 53 - 66
0.269	0.017	Dd = 23 -> Weight = 53 - 66
0.269	0.016	Dd = 28 -> Weight = 53 - 66
0.269	0.016	Mm = 1 -> Weight = 53 - 66
0.269	0.016	Dd = 24 -> Weight = 53 - 66
0.269	0.016	Region = Region1 -> Weight = 53 - 66
0.269	0.015	Region = Region1, Offday = 0 -> Weight = 53 - 66
0.268	0.016	Dddescr = Tuesday -> Weight = 53 - 66
0.268	0.016	Dddescr = Tuesday, Offday = 0 -> Weight = 53 - 66
0.268	0.015	Mm = 9, Offday = 0 -> Weight = 53 - 66
0.268	0.016	Region = Region6, Offday = 0 -> Weight = 53 - 66
0.268	0.014	Mm = 3, Offday = 0 -> Weight = 53 - 66
0.268	0.015	Dddescr = Saturday, Offday = 0 -> Weight = 53 - 66
0.268	0.015	Dddescr = Saturday -> Weight = 53 - 66
0.268	0.028	Dd = 25 -> Weight = 66 - 81
0.267	0.013	Mm = 6, Offday = 0 -> Weight = 53 - 66

Figure 5. Prediction of waste bin weight percentage based on association rules.

9. ROUTING OPTIMISATION SUBSYSTEM

In this section we describe the static and dynamic data we store and calculate for each bin, we describe the construction methodology used for the graph models, we highlight the routing particularities of Dynacargo, we outline our algorithmic approach and discuss known families of routing problems that present similar characteristics and technical limitations.

9.1 Static and Dynamic Bins' Data

At first, we classified all bins according to the type of their geographic region, in order to be able to analyze historic data (plus future data) and facilitate administrators to configure the routing subsystem. The categories we chose are general and can be applied to any municipality. They are outlined in Table 1.

Table 1. Generic Region Types

Region Type ID	General description	Regions of Nafpaktia
1	Historic Center	Historic center of Nafpaktos city (around the castle)
2	City	City of Nafpaktos (densely populated areas with blocks of flats)
3	Suburb	Suburb area of Nafpaktos city (mainly houses and small apartment buildings)

4	Town	Antirrion
5	Village – Rural area	Routes to Panw Neokastro, Paleochoraki and St Ioanni monastery
6	Remote area	Route of Apodotia.

The following **static data are stored for each bin**:

- id
- longitude,
- latitude,
- altitude,
- bin type (small or large and its capacity in lt)
- Region Type ID (1 to 6 according to the above table)
- id of fixed route that it belongs
- number in the order of collection within the fixed route that belongs
- Average daily volume growth rate (Winter)
- Average daily volume growth rate (Summer)

Additionally, we store the following **dynamic data for each bin** that are provided either by system administrators or other subsystems, such as Bins Data Gathering Subsystem or the Data Mining Subsystem:

Dynamic data by administrator

- **Day Limit:** Maximum time period (in days) that a bin cannot be serviced, depending on the seasonal period and the location of the bin.
- **Upper Limit (% volume):** If the bin fill-level exceeds this limit at the collection time, then it should be collected.
- **Lower limit (% volume):** If the bin fill-level not exceeds this limit at the collection time, then it should not be collected.
- **Waste average weight (kg) per liter** per region type.

The dynamic data as estimated for the municipality of Nafpaktia are shown in table 2. These values can be modified by the administrator whenever necessary.

Table 2. Administrator's Dynamic Data for Nafpaktia

Region Type ID	Waste average weight (kg) per lt	Lower limit (% volume)	Upper Limit (% volume)	Day Limit (winter)	Day Limit (summer)
1	0.10	20	60	3	2
2	0.10	20	60	3	2
3	0.09	20	70	5	3
4	0.08	20	70	5	3
5	0.07	20	75	7	4
6	0.06	20	80	7	4

Dynamic data by collectors

- ID Collector
- Timestamp (date and time of collection)
- Bin fill-level percentage as collected several times daily by various collectors passing by the bin, carrying a Bins Data Gathering Subsystem.

Dynamic data by DataMining Subsystem

- Timestamp of prediction (date and time of the next scheduled routes)
- Bin fill-level percentage forecasted value for the above timestamp.
- Waste weight based on the forecasted volume. It is calculated by using the waste average weight (kg) per liter per region type.

Dynamic data by refuse truck

- Actual Bin fill-level percentage collected by the refuse truck. This value is compared to the forecasted value, in order to improve the accuracy of future predictions.

9.2 Refuse Tracks' Data

For each refuse truck the administrators provide the following data:

- Registration number
- Capacity
- Average fuel consumption
- Daily availability
- Which bins can service (which bin types and/or which geographical regions)
- Parking area that it is currently parked

9.3 Graph Model

Most non-urban municipalities in Greece include geographically scattered villages or towns, thus in our model we group of a village or a town into bin clusters. For each pair of bins within a cluster the actual distance between them is calculated considering traffic restrictions, in both directions. Even if the distance of a bin pair in both directions is the same, the travel costs may not be, in case of an uphill route. For each bin cluster, we set one or more entry / exit points, usually 1, 2 or 3 for a typical village or town. By using the entry / exit points of all clusters, the landfill location and the vehicle parking space, we construct another graph. For each pair of nodes in this graph, the actual distance between them is calculated considering traffic restrictions, in both directions.

The actual distance between two geographic points is calculated by using the QGIS tool and the Open Street Map platform via the online routing API that provides. We are based on open standards and the commonly used WGS84 coordinate system, thus this procedure could be also performed by using the routing API of Google or Bing Maps.

9.4 Dynacargo Routing Problem

2100 bins and 2 bin types. 11 refuse trucks, 6 kinds of trucks. Some trucks are servicing only one bin type. Only one small truck can service bins in the historic center of Nafpaktos, because of narrow roads. This small truck is also used to collect other small bins, some of which are located at long distances, mainly due to lower fuel consumption. This small truck does not go to the landfill, but transships its waste cargo to a larger refuse truck.

All routes should begin and end in a single truck parking area. Each truck route (except the route of the small truck) must pass from the landfill once and then move directly to a parking area without servicing other bins.

9.5 Our Algorithmic Approach

Currently, we are designing our routing algorithms in order to implement and evaluate them. In this section we outline our approach.

Step1: Calculate the bins' priority

Based on bins dynamic data and the seasonal period, the priority to service a bin is calculated: 1 (do not service), 2 (desirable but not necessary to service it), 3 (must be serviced). The algorithm that calculates the priority for each bin can be parameterized by system administrators and it is described below :

- If we have reached the day limit since the last collection of the bin, then Priority =3
- If forecasted value of the bin fill-level >= Upper Limit, then Priority =3
- If Lower Limit <= forecasted value of the bin fill-level < Upper Limit, then Priority =2
- If forecasted value of the bin fill-level < Lower Limit, then Priority =1

Step2: Solve the subproblem of the small truck

- Find the best route that service all small bins with priority 3 including the small bins in the historical center of Nafpaktos (no other truck can service them) and the most distant ones (because of lower fuel consumption).
- If there is available capacity in the small vehicle, chose some extra small bins with priority 2 to include in the route of the small vehicle, preferring:
    - The bins that cause the smaller presentence increase on the initial route.
    - The bins that the next day will probably have priority 3 (ie. if current %volume + daily volume growth rate >= upper limit %volume or if tomorrow the bin will reach the collection day limit).
- Reset the load of all small bins that belong to the small truck route. Assign the total load of the small truck route to the last bin in its route, and set priority 3 for this bin. We consider this bin as the location of the waste transship to a bigger truck. The algorithm should synchronize the routes of the two trucks so as to minimize the waiting time of the truck that arrive first at the transship location.

Step3: Solve the total routing problem

The complete problem will be solved in two levels: within each cluster and in inter-cluster level.

In overall, the main routing problem is defined as finding a set of optimal routes (lowest total km and fuel consumption) for a subset of the available trucks, that begin from the parking area, service every bin of priority 3 (including the small truck node), and end up in landfill and then in the parking area, satisfying the capacity constraints of the available trucks. Depending on the available capacity of each truck, we could assign to its route some extra bins of priority 2, starting from those that cause the less percentage increase to the length of the initial route and/or those that will probably have priority 3 the next day.

Step4: Dynamic routing

- **At bin level:** The final routes will be enriched by those bins with priority 2 or 1, that are located on the route, but the algorithm did not choose. These bins will be collected by the refuse truck, only if their fill-level exceeds the upper volume limit of each bin.
- **At route level:** as the bins are collected by the refuse truck, the truck system calculates the total difference between the actual wastes in bins with the predicted values. If the collected waste is more than the predicted one, then start removing bins of priority 2, from the end of the route.

9.6 Assigning to known problem families

This specific problem is a variant of the Capacitated Vehicle Routing Problem (CVRP) where the approach methods are grouped into the following main categories [11]: Branch-and-Bound, Branch-and-Cut (hybrid methods between Branch-and-Bound and Cutting Plane methods), Set-covering based algorithms, Heuristics and Metaheuristics.

Furthermore, Dynacargo routing problem can also be approached as an Orienteering Problem (OP). The OP is a combination of vertex selection and determining the shortest Hamiltonian path between the selected vertices. The OP's goal is to maximize the total score collected, while the TSP tries to minimize the travel time or distance. Furthermore, not all vertices have to be visited in the OP. The main categories of OP are the following: [12]: Orienteering problem (OP), Team Orienteering Problem (TOP), Orienteering Problem with Time Windows (OPTW), Team Orienteering Problem with Time Windows (TOPTW).

For the implementation of our algorithms, we will be based on the library Or-Tools of Google, possibly in combination with other tools.

10. CONCLUSIONS

Sustainable growth, in regards to urban areas, requires intelligent waste collection management. Dynacargo serves this need by developing a cargo-centric waste transport management system and by implementing a fully functional instance regarding domestic waste collection in a real life large scale scenario.

This is achieved by expanding traditional fleet management functionality in two manners. One breakthrough that Dynacargo utilizes is to stream near real-time waste related information (fill level of waste bins) into the monitoring and decision support process, prior to collection from waste concentration points. If this information is not available or not efficient from a cost-benefit perspective, it is substituted by historical data in order to predict waste bins status. The second breakthrough that Dynacargo introduces is active citizen involvement, by turning them into active information producers and consumers. Dynacargo utilizes low-cost durable RFID tags, along with alternative network protocols such as DTN, is 4G-ready and utilizes dedicated dynamic routing algorithms in order to minimize telecommunication and hardware costs.

This paper presents the scope of the Dynacargo project, the architectural modules and the interrelations between them, as well as the research issues and development progress of some significant modules, namely the Bin Subsystem, the Data Mining Subsystem and the Routing Subsystem.

11. ACKNOWLEDGMENTS

This work has been financially supported by the Greek General Secretariat of Research and Technology and European Union under the project “11SYN_10_456: Dyanacargo”.

12. REFERENCES

[1] Asimakopoulos G., Christodoulou S., Gizas A., Triantafillou V., Tzimas G. and Vasilopoulos N. (2014). Functional specifications and architecture of a dynamic routing system for urban waste collection using real-time information. IADIS 13th International Conference on WWW/Internet, 25-27 Oct 2014, Porto, Portugal, pp. 203-210.

[2] Al Mamun M.A., Hannan M.A., Hussain A., Basri, H. (2013). Wireless Sensor Network Prototype for Solid Waste Bin Monitoring with Energy Efficient Sensing Algorithm. *IEEE 16th International Conference on Computational Science and Engineering*.

[3] Arebey M., Hannan M A, Basri H., Begum R A, Huda A. (2010). Solid Waste Monitoring System Integration based on RFID, GPS and Camera. *Proceedings of IEEE Intelligent and Advanced Systems (ICIAS)*

[4] Faccio M, Persona A and Zanin G. (2011). Waste collection multi objective model with real time traceability data. *In Waste Management, Elsevier,* Vol. 12, No. 2,pp 391-405.

[5] Gomes T., Brito N., Mendes J., Cabral J. and Tavares A. (2012). WECO: A wireless platform for monitoring recycling point spots. *Proceedings of 16th IEEE Mediterranean Electrotechnical Conference (MELECON)*.

[6] Gukhool O., Bokhoree C., Mohee R. and Jamnejad G. (2008). Solid Waste Collection Optimization using a Route Time Approach: A case study for an urban area of Mauritius, *23rd Int. Conf. on Solid Waste Technology and Management, Philadelphia PA, p501*.

[7] Johansson Ola (2006). The effect of dynamic scheduling and routing in a solid waste management system. *In Waste Management,* Vol. 26, No. 8,pp 875 – 885.

[8] Municipality of Athens. (2003) Estimation, Evaluation and Planning Of Actions for Municipal Solid Waste Services During Olympic Games 2004. Municipality of Athens.

[9] Nuortio T, Kytöjoki J, Niska H and Bräysy O (2006). Improved route planning and scheduling of waste collection and transport. *In Expert Sys Appl,* Vol. 30, No. 2,p 223-232.

[10] Roshan I. and Akshai M. (2013). SVASTHA: An Effective Solid Waste Management System For Thiruvalla Municipality in Android OS. *Proc. of IEEE Global Humanitarian Technology Conf. South Asia Satellite*.

[11] Toth P. and Vigo D. (2001). The vehicle routing problem. Society for Industrial and Applied Mathematics, Philadelphia, PA, USA.

[12] Vansteenwegen P., Souffriau W., Oudheusden D. V. (2011). The orienteering problem: A survey. European Journal of Operational Research, Vol. 209, Issue 1, pp. 1-10.