Architecture and Implementation Issues, Towards a Dynamic Waste Collection Management System

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ABSTRACT
Dynacargo is an ongoing research project that introduces a breakthrough approach for cargo management systems, as it places the hauled cargos in the center of a haulage information management system, instead of the vehicle. Dynacargo attempts to manage both distribution and collection processes, providing an integrated approach. This paper presents the Dynacargo architectural modules and interrelations between them, as well as the research issues and development progress of some selected modules. In the context of Dynacargo project, a set of durable, low cost RFID tags are placed on waste bins in order to produce crucial data that is fed via diverse communication channels into the cargo management system. Besides feeding the management system with raw data from waste bins, data mining techniques are used on archival data, in order to predict current waste bins fill status. Moreover easy-to-use mobile and web applications will be developed to encourage citizens to participate and become active information producers and consumers. Dynacargo project overall aim is to develop a near real-time monitoring system that monitors and transmits waste bins' fill level, in order to dynamically manage the waste collection more efficiently by minimizing distances covered by refuse vehicles, relying on efficient routing algorithms.

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.

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

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1. INTRODUCTION
Nafpaktia is a typical example of how solid waste collection is managed throughout the country, as waste collection occurs on regular time intervals by following fixed routes. The waste collection scheme and all related decisions are drawn based solely on personnel experience.

This "rule of thumb" approach sometimes displays an unacceptable result, as it was found that in some cases overfilled waste bins were uncollected for some days, while at the same time other unfilled bins were collected anyway. These inaccuracies result in citizen dissatisfaction and a noticeable cost increase. In the Municipality of 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 factor for reducing the cost is to minimize the distance and duration of the 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%. Dynacargo project (Dynamic Cargo Routing on-the-Go) aims at developing 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
At the moment, several approaches exist that tackle issues regarding waste collection management and especially information collection at the point of waste disposal [2,3,4, 5,7,9,10]. However, none of these solutions can be applied as-is in the Dynacargo case. Most of them are expensive and they do not match the Dynacargo functional requirements, while most of them deal with the problem of collecting recyclable waste, which can be collected at less frequent intervals.

Although Dynacargo aims at automating the waste collection process as existing approaches do, it also exhibits major differences when compared against such solutions. The differences arise mainly due to the Dynacargo architecture, which builds on the concept of a generic multipurpose cargo-based dynamic vehicle routing system that takes into account dynamically changing cargo that needs to be collected from disperse points. This implies that Dynacargo does not only serve as a data collection system that transmits data from waste bins to a central server, but utilizes this data in order to achieve optimized vehicle routing in a dynamic manner during the waste collection process via decision making system.

A major breakthrough that Dynacargo introduces is the utilization of a diverse set of data transmission techniques in order to ensure that data is sent from points of collection to the system in the most efficient manner. Rather than relying on GSM, which induces fixed telecom costs, Dynacargo adapts Delay-Tolerant Networking concepts in order to transmit data from disperse collection points to the system. In order to achieve this, a set of existing public commuters serve as data hosts that transport data as they execute unaltered standard procedures.

3. NAFPAKTIA AS CASE STUDY

The functional requirements of Dynacargo resulted 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. It has geographic and demographic peculiarities that make it ideal as a pilot Municipality for Dynacargo. It includes a coastal city with narrow busy streets in the historic center, coastal towns and villages whose population increases substantially during the summer months, but also mountain remote villages (up to 120 km. away) with a few dozen residents. The network coverage and frequency of public bus routes are very diverse among the areas of the municipality. Finally, it supports the transshipment of waste from a small to a big refuse truck. An as-is analysis was performed initially in order to formally document the current waste management process. A set of indicative waste collecting routes were selected in a way that ensures the incorporation of peculiarities and modeled on Google Earth (Figure 1). The analysis included available waste collection historical data and information regarding related processes.

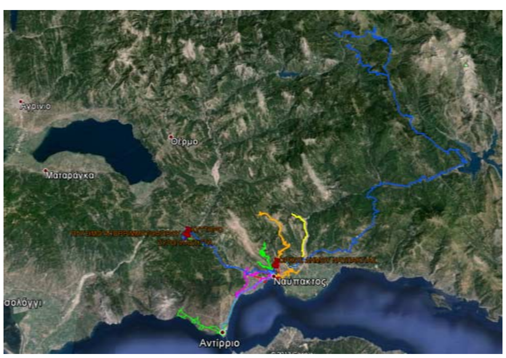

Figure 1. Indicative waste collection routes for Nafpaktia.

4. USERS & USE-CASE MODELS

The main user groups realized throughout the analysis are: waste collection related municipal services, system administrators, truck drivers, bins' data collectors and individual citizens.

In order to reassure the accurate Dynacargo operation when used as a prediction system, information regarding waste bin fill level must be acquired at brief intervals from as many as possible waste bins. In order to achieve this goal, existing organized transportation systems are utilized 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 regularly. A Data Collector can be 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. Moreover, citizens can improve the operation of the system by reporting fill-level through 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.

After collecting and analyzing the users' functional requirements, we have constructed several application scenarios that are divided into two categories: *Full-scale Application Scenarios* and *Pilot Scenarios* (scenarios that will be demonstrated during the project). Based on the full-scale scenarios, use-case models defining use cases for each subsystem were constructed, including the vast majority of functional requirements along with some non-functional requirements. We have constructed six major use-case models, 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

Based on the functional requirements and the use case models, the most significant Dynacargo structural components were pinpointed and designed and furthermore decomposed into subsystems and smaller functional units. Operations, roles and significant logical relationships with other subsystems were defined for each subsystem.

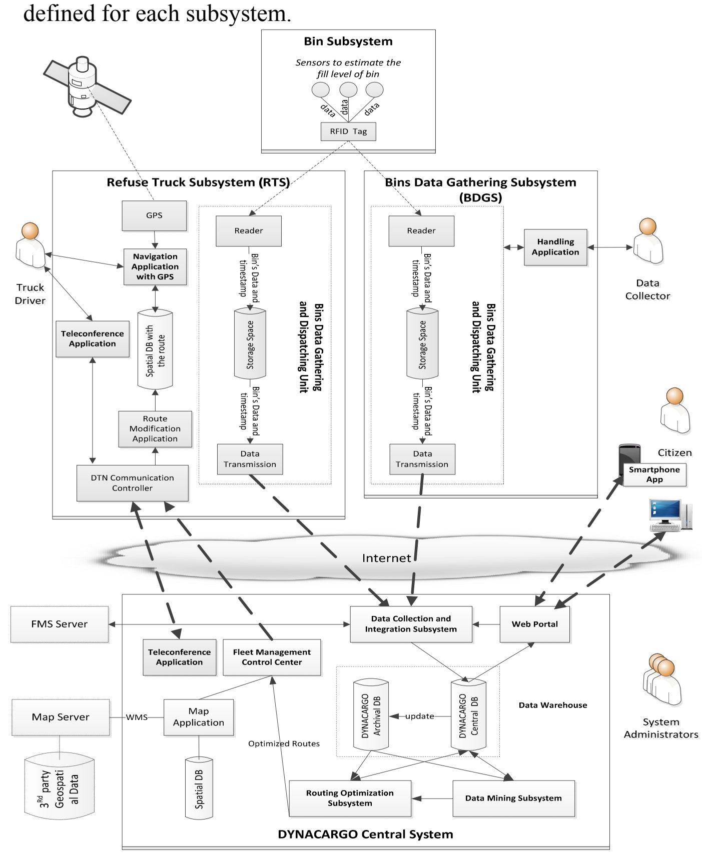

Figure 2. Dynacargo Architecture.

Dynacargo specifications were derived after thorough analysis of the waste collecting process as it is implemented by Nafpaktia municipality. However, the Dynacargo architecture is designed in a manner that allows its utilization as a generic cargo-based routing system along with the inherited ability to be adapted 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: Special equipment (sensors) that estimates the waste bin fill level and collects, stores, and transmits bins data.

Bins Data Gathering and Dispatching Unit: A unit that communicates through a short range network with the Bin Subsystem and dispatches the collected information (Bin's Data) to the Central System, through a long range network. It can be installed at passing vehicles and consists 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.

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

The bin subsystem consists of three building blocks: the fill sensing unit, the active RFID tag for data transmission, and the protective enclosure. 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 advanced sensing approaches. The harsh environmental conditions (e.g., humidity, temperature, and dust) can significantly affect the sensor measurement accuracy and reliability.

A comparison of various solutions including infrared proximity sensors, optical sensors and ultrasonic sensors, indicated that ultrasonic sensors appear to be the most suitable solution for the purpose of the presented architecture taking into account the aforementioned conditions. The ultrasonic sensors are advantageous in providing ranging measurements independently of the contained objects, thus making possible the corresponding translation into fill level measurements. Since the resolution of the ultrasonic sensors is only centimeters (less than an inch) the selected solution can offer fine-grained accuracy. 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 are to be used. An analog output is provided for connecting the sensing units to the data transmission unit of each bin, thus the active RFID tag.

Active RFID tags have been selected as the data aggregation and transmission unit for the bin subsystem. The selected tags can operate with a standard 3.3V battery providing a lifetime of more than 5 years (that equals to millions of beacon transmissions). The employed active tags offer extra I/O pins for communicating with external devices, thus 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. The tag itself supports various operating modes, including standard beacons at programmable time intervals, sleep, wake up at regular intervals and also wake up at external trigger. The combination of the above operating modes allows the extension of the entire bin subsystem energy lifetime, since minimal power consumption occurs when the tag operates in sleep mode and the sensor is not powered up. When the tag is awake, it powers up the sensors and temporarily stores their values in its internal memory.

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. 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.

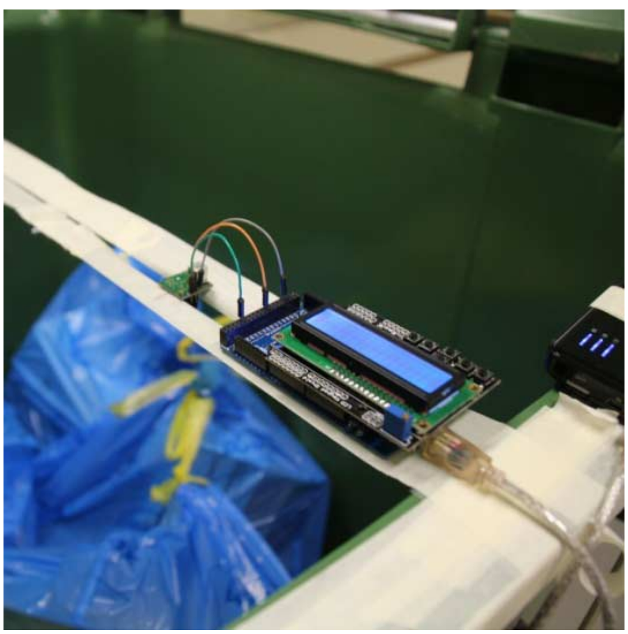

Figure 3. Experimental setup with sensors and an Arduino board for control

System installation and maintenance, ensuring radio coverage, and retaining network formation can become an unmanageable task. The Dynacargo project opts for low-range, point-to-point communications based on RFID technology so as to cope with these issues. Vehicles roaming around the city and equipped with readers collect the information from the bins. In order to cope with increased telecommunication costs and infrastructure upgrades, these mobile sinks defer transmissions until an Internet connection becomes available. The Delay Tolerant Networking paradigm ensures that the information is retained in the bins, until a mobile sink passes nearby and then in the sinks, until an Internet connection is available.

7. 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 is quite exploratory, as the parametrization of the applied methods and their analysis in order to select the more efficient ones, is a process quite empirical. The research team tried to execute different scenarios in order to analyze the behavior of existing data mining methods and provide the rules that arise wherever is possible.

Data mining algorithms study and results visualization

The procedure followed in order to study and fine tune the data mining algorithms within the scope of the project, as well as the visualization of the results, is discussed below. 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. When creating the mining structure the variables included in the analysis were chosen. Furthermore, each variable type was defined in order to be effectively handled by the data mining algorithm. For example, some variables are continuous space such as dates, some are distinct and some must be discretized for the sake of the analysis at specific intervals. Also, a variable must be defined as the key which imposes distinctness between different records.

In the scope of the subsystem a clustering model was defined, as well as variants 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), make the distinction between them 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. With this configuration we attempted to find the logical expressions that link data together. Also, a classification took place according to the distance between the waste bins and investigated how this affects the total cost.

Besides the above, at the Analysis Server a cube was constructed 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. PivotViewer was used to implement the main querying interface, since it 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, while the animations and natural transitions provide context and prevent users from feeling overwhelmed by large quantities of information. The PivotViewer enables users to interact with thousands of objects at once, and sort and browse data in a way that helps them see trends and quickly find what they are looking for. In PivotViewer, variables filters can be applied depending on the range of each one. Filters can be applied simultaneously to many variables. Besides filtering, the data can be sorted on any variable without the need of a filter. 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.

8. ROUTING OPTIMISATION

In this section we describe the static and dynamic data we decided to store and calculate for each bin, we present how we construct the graph models, we highlight the routing particularities of Dynacargo and match them to known families of routing problems that present similar characteristics and technical limitations.

8.1 Static and Dynamic Bins' Data

For each bin we store the following static data: longitude, latitude, altitude, bin type, bin capacity. Moreover, we identify some dynamic data for each bin that can be provided either by system administrators or other subsystems, such as Bins Data Gathering Subsystem or the Data Mining Subsystem:

- Bin fill-level that it is collected many times daily from several collectors.
- Bin fill-level predicted value at the time of routes, provided by the Data Mining Subsystem.
- Actual bin fill-level collected by the refuse truck. This value is compared to the predicted value and used for more accurate future predictions.
- Maximum time that a bin cannot be serviced, depending on the seasonal period.
- Specific days and / or hours that the bin must be serviced, depending on the seasonal period.
- Bin priority (1 to 3). Based on other dynamic data and the seasonal period, the priority to service a bin will be: 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.

8.2 Graph Model

Because most non-urban municipalities in Greece contain geographically scattered villages or towns, our model will group nearby bins into bin clusters. For each pair of bins within a cluster the actual distance between them is calculated considering traffic restrictions, in both directions. Moreover, even if the distance of a bin pair in both directions is the same, the travel costs may not be. For each bin cluster, we set one or more entry / exit points. The entry / exit points of all clusters, the landfill location and vehicle parking spaces are modeled as the nodes of another graph. For each pair of nodes in this graph, the actual distance between them is calculated considering traffic restrictions, in both directions.

The calculation of actual distance between two geographic points is carried out by using the QGIS tool and the Open Street Map 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.

8.3 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 tranships its waste cargo to a larger refuse truck.

All routes should begin and end in a truck parking, and in our system there can be more than one parking areas and selected parking areas for each refuse truck. This information is provided for each refuse truck, as well as which trucks are available every day. 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.

8.4 Our Algorithmic Approach

Currently, we are designing our routing algorithms in order to implement and evaluate them. In this section we outline our approach. At first we are going to solve the subproblem of the small truck which will service all small bins with priority 3, that are located in the historical center of Nafpaktos and are the most distant ones. Depending on the available capacity of the truck, assign to its route some extra small bins of priority 2, starting from those that are closer to the initial route.

Afterwards, reset the load of all small bins that belong to the small truck route, and solve the complete problem with the other available trucks, where the small truck appears as a separate node with its load. The exact location of this node should be on the route from the last bin serviced by the small truck and its depot. The optimal position of this node (which is the location of the waste transship to a bigger truck) will be calculated by the algorithm. 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. The complete problem will be solved in two levels: within each cluster and inter-cluster.

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 at parking areas, go through each bin of priority 1 at least once, and end up in landfills and then in a parking area, satisfying the capacity constraints of the available trucks and the maximum time of any route. It should also be taken into account the issue of transhipment of the small truck. Depending on the available capacity of each truck, assign to its route some extra bins of priority 2, starting from those that are closer to the initial route. At this point, we will examine ways to optimize the selection of best bins of priority 2 (or even 1), relying on the prediction of these bins fill-level for the next days.

8.5 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. As a consequence, the OP can be seen as a combination between the Knapsack Problem and the

Travelling Salesperson Problem (TSP). 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. Determining the shortest path between the selected vertices will be helpful to visit as many vertices as possible in the available time. 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. The aim of this library, unlike other constraints programming libraries, is not to provide a complete set of constraint-based algorithms solutions. Conversely it provides a tool for initial analysis and programming on which we can build solutions for more specific problems.

9. CONCLUSIONS

Intelligent transportation systems constitute key components for ecologically sustainable development in urban spaces. Dynacargo project aims at developing a cargo-centric transport management system and demonstrates it in the case of urban solid waste collection management. Dynacargo extends and expands existing fleet management system functionality in two directions. The first direction is to fuse into the monitoring and decision support process near real-time waste related information (fill level of waste bins) before refuse truck visits a collection point. Alternatively, if this information is impossible or not justified on a cost-benefit basis, historical information is utilized in order to predict waste bins fill status, using data mining technics. The second direction is to encourage end users (i.e. citizens) to participate and become active information producers and consumers. Dynacargo will utilize low-cost, durable units as RFID tags, explore alternative network protocols like DTN, will be 4G-ready and will utilize dedicated dynamic routing algorithms in order to minimize telecommunication and hardware costs. In this paper, we outline the system functional requirements derived from the needs of the main user groups, illustrate some use case models and present the major architectural parts of Dynacargo, their decomposition into subsystems and smaller modules. Now we are in the phase of deciding the implementation details of each module and integrate them in a compact system.

10. ACKNOWLEDGMENTS

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11. 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.