Smart system for freight distribution planning.

Based on variable neighbourhood search and tabu search metaheuristics

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SISTEMA INTELIGENTE DE PLANIFICACIÓN DE RUTAS PARA LA DISTRIBUCIÓN DE MERCANCÍAS. BASADO EN LAS TÉCNICAS METAHEURÍSTICAS, BÚSQUEDA DE ENTORNO VARIABLE Y BÚSQUEDA TABÚ

RESUMEN

- Este artículo presenta un innovador sistema inteligente de ayuda a la toma de decisiones para las empresas dedicadas a la distribución de mercancías. La solución informática permite gestionar y planificar las rutas de transporte de mercancías basado en un sistema de información geográfica que permite el cálculo real de las distancias entre dos o más nodos de la red.
Con el crecimiento de las ciudades, la carga y descarga de mercancías es una función prioritaria de cuyo funcionamiento depende, en buena medida, la eficacia y la eficiencia de los sistemas tecnológicos implementados. El funcionamiento actual de la carga y descarga en la ciudad se valora, en términos generales, como no sostenible por los elevados costes medioambientales, sociales y económicos que comporta para el conjunto de la ciudad.
Es por ello que, actualmente, los Sistemas Inteligentes de Transporte en entornos de las ciudades inteligentes están experimentado un notable auge durante los últimos años.
El sistema desarrollado es una innovadora e intuitiva aplicación que permite un fácil aprendizaje de las funcionalidades y que se adapta sencillamente a cualquier caso de estudio definido por el usuario.
Para la resolución del problema, el sistema incorpora un algoritmo basado en una combinación de las metaheurísticas búsqueda de entorno variable y búsqueda tabú, teniendo en cuenta las características encontradas en la realidad con el objetivo de reducir los costes totales de la distribución y mejorar la eficiencia de las empresas. Este algoritmo es el resultado de un trabajo de investigación ligado a toda la trayectoria de los investigadores en el ámbito de la distribución urbana de mercancías.
- Palabras clave: Distribución de mercancías, sistema de ayuda a la toma de decisiones, problemas generales de planificación de rutas, búsqueda de entorno variable, búsqueda tabu.

ABSTRACT

This article presents an innovative and smart decision support system for companies dedicated to the freight distribution. The computer solution allows to manage and schedule transport routes of goods based on a geographic information system that enables the calculation real of distances between two or more nodes of the network.

With the growth of cities, the loading and unloading of goods is a priority function whose operation depends to a large extent, the effectiveness and efficiency of the implemented technology systems. The current operations of loading and unloading in the city is valued, in general terms, as unsustainably high costs for environmental, social and economic behavior for the whole city. That is why, today, the Intelligent Transportation Systems in urban environments Smart are experienced a remarkable boom in recent years.

The system developed is an innovative and intuitive application which enables an easy learning of the functionalities and may be simply adapted to any case study defined by the user.

For the resolution of the problem, the system incorporates an algorithm based on a combination of the metaheuristics, variable neighbourhood search and tabu search, taking into account the characteristics encountered in real life with the objective of reduce total costs of distribution and improve the efficiency of companies. This algorithm stems from research activities devoted to urban freight distribution during the whole professional history of researchers.

• **Keywords:** Freight distribution, decision support system, general vehicle routing problem, variable neighbourhood search, tabu search.

1. INTRODUCTION

In the field of Decision Support Systems (DSS), transportation management systems are undoubtedly a mature market, and transportation routing and scheduling solutions evolve continuously. Nowadays, most companies that have a fleet of more than 20 vehicles are operating under a routing and scheduling software license. Firms carefully appraise the great business impact in terms of optimized routes and schedules that minimize kilometers and costs.

The logistics of the urban transport of goods has an essential dimension so that distribution requires efficient systems and the process must be effective and clean. Therefore, it is necessary to efficiently manage urban logistics and improve connections in order to ensure effective distribution [1]. Freight transport by means of vehicles over 3.5 tonnes represents about 10% of the total traffic within urban areas. If lighter vehicles are included, the percentage increases considerably. This is a significant volume of daily operations (in Barcelona, according to the city council, the transport of goods accounts for 16 % of daily trips) [2].

In recent decades, the DSS has emerged as a computer-based approach assisting decision-makers to address semi-structured problems by allowing them to use data and analytic models [3]. The interest in the development of DSS is due to the complications involved in resolving these types of problems and the complex requirements necessary to carry out feasible solutions to help transport companies to make decisions effectively and manage their work efficiently.

The European Union has recently identified some issues to be considered when implementing advanced DSS. The interface between long-distance and last-mile freight transport should be organized more efficiently. The aim would be to allocate the shortest routes –in terms of distance- to routes with few orders to reduce inefficiencies. This could be performed with low emission urban trucks. The use of electric, hydrogen and hybrid technologies would not only reduce air emissions, but also noise, allowing a greater portion of freight transport within urban areas to take place at night time. This would ease the problem of road congestion during morning and afternoon peak hours [4].

To address this situation, the European Commission's White Paper on Transport contains a roadmap of 40 concrete initiatives for the next decade in order to build a competitive transport system that will increase mobility and remove major barriers in key areas like fuel consumption [5]. At the same time, the proposals will dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050. Indeed, at least a 40% cut in shipping emissions (gasoline and diesel consumption makes up 95% of energy use in road transport) needs to be achieved to contribute to a 60% cut in transport emissions as a whole by the middle of the century.

For these reasons, an integrated approach that combines routing algorithms with functions of Geographic Information Systems (GIS), database storage technologies and modeling tools can represent an important competitive advantage [6, 7]. This combination provides a platform which is able to manage large volumes of data and provide visual feedback in the form of maps [8]. The main contribution of this paper is to propose an intuitive tailored decision tool for urban shipments by integrating the essential features of this type of complex problems.

The motivation of this paper originated with the growing number of logistics and transportation firms in the region of Aragón (Spain). With an area of more than 12M m^2, the Logistics Platform of Zaragoza is the largest logistics premises on Europe. The principle characteristic of PLAZA is that it is based on an intermodal transport centre (railways, roads, and air routes), a combination which activates capacities which make Zaragoza one of the most important logistical cities in Europe, with connections to the most relevant European production and consumer centers.

The problem considered in this article is known as the General Vehicle Routing Problem (GVRP). This problem concerns the urban distribution of goods based on multiple requirements and complexities encountered in the real world such as time windows, capacity constraints, compatibility between orders and vehicles, maximum number of orders per vehicle or not returning to the depot [9]. The aim will focus on the difficult goal of helping traffic managers of freight transport companies to find solutions that reduce operational costs of distribution routes so that the activities of pick-up and delivery are planned in advance.

Although there are many studies about routing problems, there are very few papers in the literature dealing with problems that include several variants of the classical Vehicle Routing Problem (VRP) introduced by [10]. The majority of papers only study one or two variants of the classical problem as the vehicle capacity and the time window imposed to serve to the customers [11].

2. PROBLEM DESCRIPTION

The problem consists of the freight distribution in large urban areas taking into account the real characteristics encountered in companies and trades. Given a fleet of vehicles and a set of customers scattered over a geographic area, the system must be able to achieve a feasible solution that reduces the total cost of the problem. The objective is to reach a solution with the minimum number of vehicles and reduce as much as possible the total distance traveled. The model of the problem can be seen as a combination of:

- CVRP: Vehicles have a maximum limit of capacity [12].
- VRPTW: Each customer must be serviced in a specified time interval [13].
- SDVRP: Certain orders can only be carried out by specific vehicles [14].
- VRPPD: Customers may receive and send goods [15].
- VRPB: The goods that leave the depot must be delivered to customers and the goods that are picked up from customers must be transported to the depot [16].
- OVRP: Vehicles are not required to return to the depot after visiting the last customer [17].
- Load balance between routes: Limit to the number of orders transported by each vehicle [18].

One route is defined as an ordered sequence of customer requests that the same vehicle has to distribute. All vehicles begin their routes at the depot but they have no obligation to return to the depot. Some routes can end at the driver's home. The ending points for each vehicle must be initially introduced. From the model point of view, this kind of nodes is considered as "orders" without goods. Also, each vehicle has its own characteristics such as the type of load that can be transported and its maximum capacity by weight, volume and length.

Orders are customer requests of goods to be picked up or delivered at a certain geographic point during a specific time window. Both the service time (required time to realize the load or unload operation) and the time window are imposed by the customer in advance. If a vehicle arrives before the start of the time window, it has to wait before serving the node. Upon doing the service, the vehicle must leave the node. A vehicle is not permitted to arrive later than the end of the time window.

Each customer can be visited more than once by different vehicles, since a customer can request more than one order. Additionally, there are orders where vehicles have to pick up goods at a pickup node and deliver them to a delivery node without having to go through to the depot.

A maximum of orders per vehicle is established to achieve a balanced load between vehicles in order that all drivers distribute a similar number of orders independently of the cost. This characteristic ensures a fair and well-balanced treatment of all drivers of the company. In some cases, when using a small value of this variable, this constraint usually yields biased results due to hard conditions. This can be avoided by adjusting this variable to a higher value.

The GIS is used to obtain the real distance between customers since distances are short in urban areas and it is fundamental know the exact distance. Also, it is necessary to determine the geographic position (longitude and latitude) of each customer in order to calculate the distance and the required time to go from one point to another. The distance is only calculated between orders that are compatible to go on the same route. Previously, the problem is divided by means of geographical clusters according to the number of daily orders, and a check on the constraints of capacity, compatibility and time are carried out to obtain compatible sets of orders.

3. RESOLUTION ALGORITHM

There are commonly three approaches to cope with the problem: firstly, a priori approach in which a decision-maker provides preferences for the different objectives; secondly, an interactive approach in which the decision-maker's choices are made during the problem solving process; finally, some authors use a posterior approach, that is, generate first a set of potentially non-dominated solutions and then choose among them.

The problem is highly constrained and the search space is likely to contain many solutions such that it is impossible to go from one solution to another using a single neighborhood structure. Because of this, our algorithm is intended as an interactive approach which lets users select those settings and solutions that best suit them.

Metaheuristics are strategies for designing heuristic procedures to solve complex problems through a search process in a certain space of alternative solutions. Metaheuristics Variable Neighbourhood Search (VNS) and Tabu Search (TS) have been adapted to solve the problem.

VNS is a metaheuristic for solving complex problems whose basic idea is systematic change of neighborhood within a local search [19] while TS is an intelligent search method that guides a local search procedure to explore the solutions space beyond the local optimum [20]**.** The algorithm developed comprises two differentiated calculation phases:

- Route construction phase: In this phase a quick initial feasible solution is built satisfying the constraints imposed.
- Improvement phase: The solution is optimized in terms of distance and the number of vehicles used.

The route construction method consists of allocating orders to vehicles taking into account the limits of load balance between routes determined according to the number of orders. The system begins by creating routes sequentially one by one, selecting the first order to be inserted under the following criteria:

- Latest hour of arrival of the vehicle to the depot.
- Close earliest of the start time to serve a customer.
- Smallest width of time window after the arrival to the customer.
- Effective distance from the customer to depot.
- Lowest value of the sum of the above criteria for each order.

This last is the most common criterion because it includes the rest. Following, orders are inserted until the route is not feasible or it has reached the maximum number of orders allowed per route. The process finishes when there are no orders without a route, at which point a solution has been created. The insertion of the rest of the orders is based on two criteria:

- Greatest temporal margin: Order is inserted in the position of the route whose temporal margin is greater.
- Shortest distance: Choice of an order in which the distance of the route is less.

To improve the problem, it is applied a hybrid method that combines the extended variant general VNS which uses more than one neighborhood structure in a local search and the TS metaheuristic used in the shaking phase of the general VNS to eliminate randomness and to diversify the exploration neighbourhood, avoiding the decrease in local minimums and allowing the search for better solutions [21].

The mechanisms for the generation of customer movements between routes used in this algorithm are the well-known intra-route operators OR-OPT, IOPT, and the inter-route operators ICROSS and 2-OPT*. To define a neighbourhood search, a sequence of operators with their respective configurations is specified. The metaheuristic process is based on the use of a neighbourhood that exchanges segments. The final state of each operator of a neighbourhood determines the subsequent execution of the following neighbourhood. Therefore, a good configuration of operators helps to obtain one solution or another. The algorithm of the hybrid method can be outlined as illustrated in Fig. 1.

4. COMPUTER TOOL

The tool is a web application aimed at managing logistics distribution of goods for transport companies. This tool automatically obtains routes that vehicles have to use to distribute goods to meet customer requests. This application provides the calculation of the routes and the data processing relative to the organization, allocation of restrictions procedures, load management and modification of the routes.

When this tool was developed, it was considered that the target audience did not have a wide knowledge of the modeling and optimization aspects of routing problems. Therefore, great efforts were made to provide a user-friendly application allowing an easy use of data. Integrated Development Environments (IDE) Eclipse, Toad® for Oracle and Microsoft Visual Studio® were used to implement the system. This tool is independent of a specific technological platform because it was developed as a web application using only a web browser. To implement the algorithm to calculation routes, the C++ language, one of the most efficient and rapid languages for generating a large amount of computer calculations was chosen.

4.1. ARCHITECTURE

The tool is hosted on an Intranet at a central server and a permit is required for access. The access to all the maintenance and management of the application is provided by the web browser. The system is composed of three components:

- The DataBase (DB), implemented with a Relational DB Management System (RDBMS).
- The optimization routes algorithm.
- The Graphical User Interface (GUI).

The GUI is divided into two parts. One part allows the user to execute the optimization routes algorithm and other functions to edit or visualize the stored data in the DB, while the other part helps the user to manage the organization data of the enterprise. A schematic representation of the tool functionalities and its behavior are shown in Fig. 2.

On the one hand, the 'main procedures' module interacts with the enterprise organization data and the user can modify, create, visualize, delete and activate data. This module is based on text fields, data lists and buttons to execute several actions. On the other hand, the 'functional procedures' module is based on windows with graphic elements and works

Initialization: Select the set of neighbourhood structures N_k that will be used in phase 2
Select the set of neighbourhood structures N_j that will be used in phase 3
Find an initial solution s
Choose a stopping condition

Repeat: The following until the stopping condition is met:
(1) Choose $k \in \{1, \dots, k_{max}\}$
(2) Generate a new solution $s' \in N_k(s)$ by Tabu Search
(3) Local search: Choose $j \in \{1, \dots, j_{max}\}$
Apply VND with s' as initial solution
Denote with $s'' \in N_j(s')$ the new solution obtained
(4) Move or not: If the new solution s'' is better than s, move there $(s \leftarrow s'')$

Fig. 1: Algorithm of the hybrid method

with orders, resources (drivers and vehicles), their corresponding restrictions and the assignation of orders to resources. In this module, the optimization algorithm is executed and the routes solution is visualized on graphical maps by means of the GIS.

4.2. ESTRUCTURE OF THE DATABASE MANAGEMENT SYSTEM

Internet and the web technology have been used to develop this DSS. This means that the entire application has been implemented using a web server, languages such as HTML or PHP and a DB managed by a RDBMS to store all the necessary information.

In our case, the RDBMS used was Oracle version 10g and the languages used to manage the DB were SQL and PL/SQL. The system generated includes 37 DB tables and 73 procedures specifically elaborated for this project classified in 7 sets: daily orders, resources, optimization, constraints, enterprise organization, maps and other utilities.

Other important aspect is how the exact distance between two geographical nodes is calculated. The tool uses API (application programming interface) to calculate distances. This API is not free when the number of requests is very large or when an economic profit is obtained from using it, so a storage system was designed. A procedure was developed that asks the API for the latitude and the longitude of each geographic node in WGS84 format and then stores the result in the DB.

4.3. GRAPHICAL USER INTERFACE

The main purpose of a GUI is to allow an easy, understandable and efficient access to all the functionalities of the system. Thus the following usability characteristics were taken into account: robustness, consistency, compatibility, scalability, interactivity and intuitiveness [22]. This tool was designed to be used on PDAs and mobile phones, so it must be accessible on devices with touch screens.

Technologies Java Server Pages and Struts version 2.0 were used to create a dynamic web content since enable a rapid development of web-based applications that are platform independent. Other technologies were used to provide a more attractive look and functional such as Javascript, Ajax, JQuery and CSS.

The GUI is divided into two sections, one called 'maintenance and management of permanent data' and corresponds to the 'main procedures' module; and the other called 'management of resources' and corresponds to the other module and used for the type of data. A window of the first section is shown in Fig. 3. The functions to manage and maintain the data are the typical of edition: insert, query, modify, and eliminate registers.

At the top of the window, there is a filter that is used

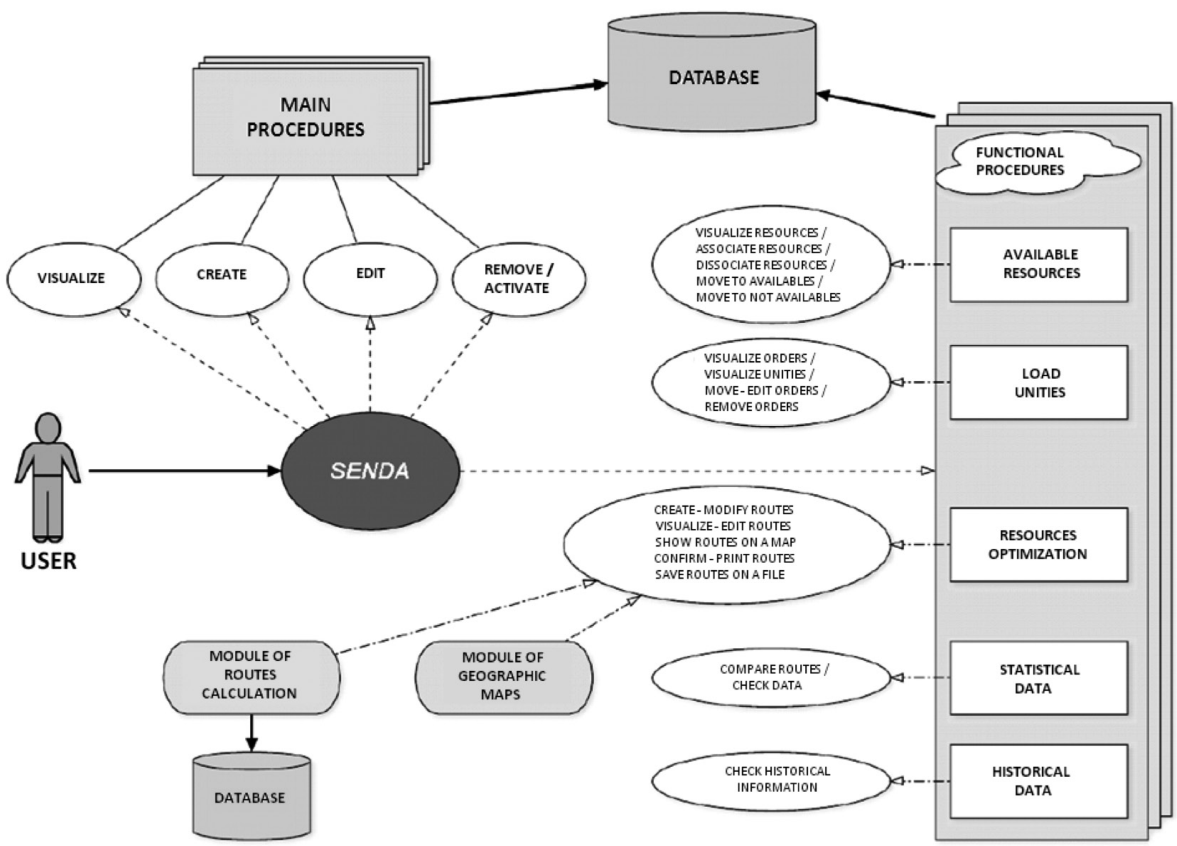

Fig. 2: Schematic representation of the application functionalities

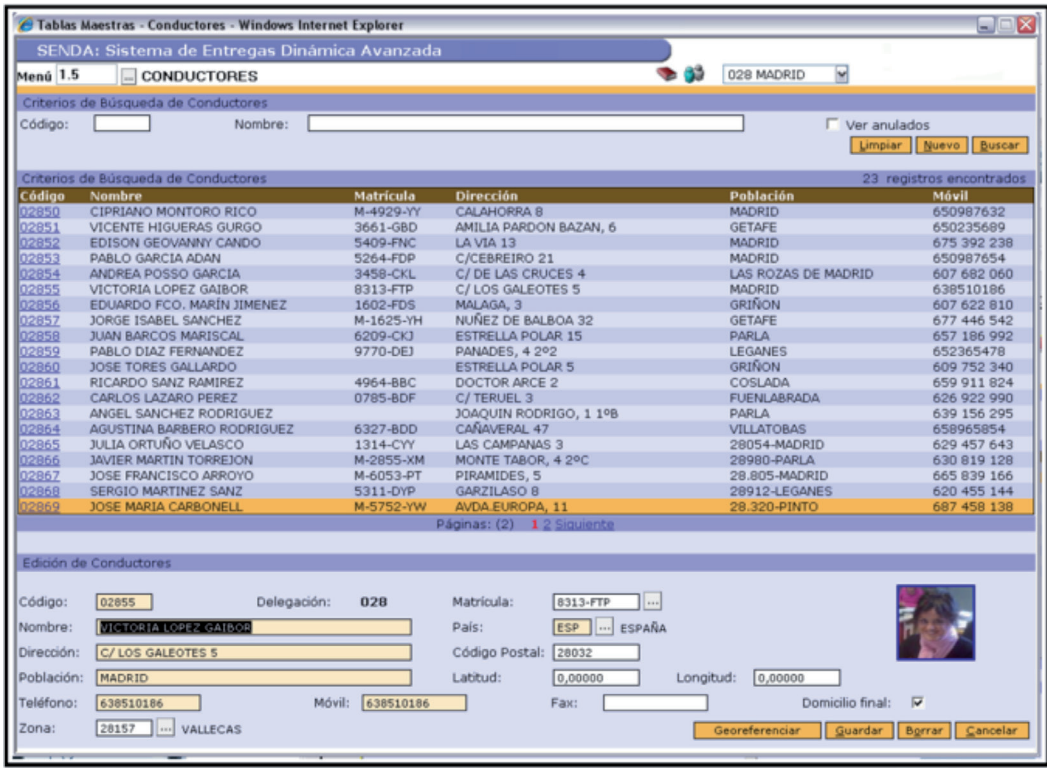

Fig.3: The maintenance and management window of data

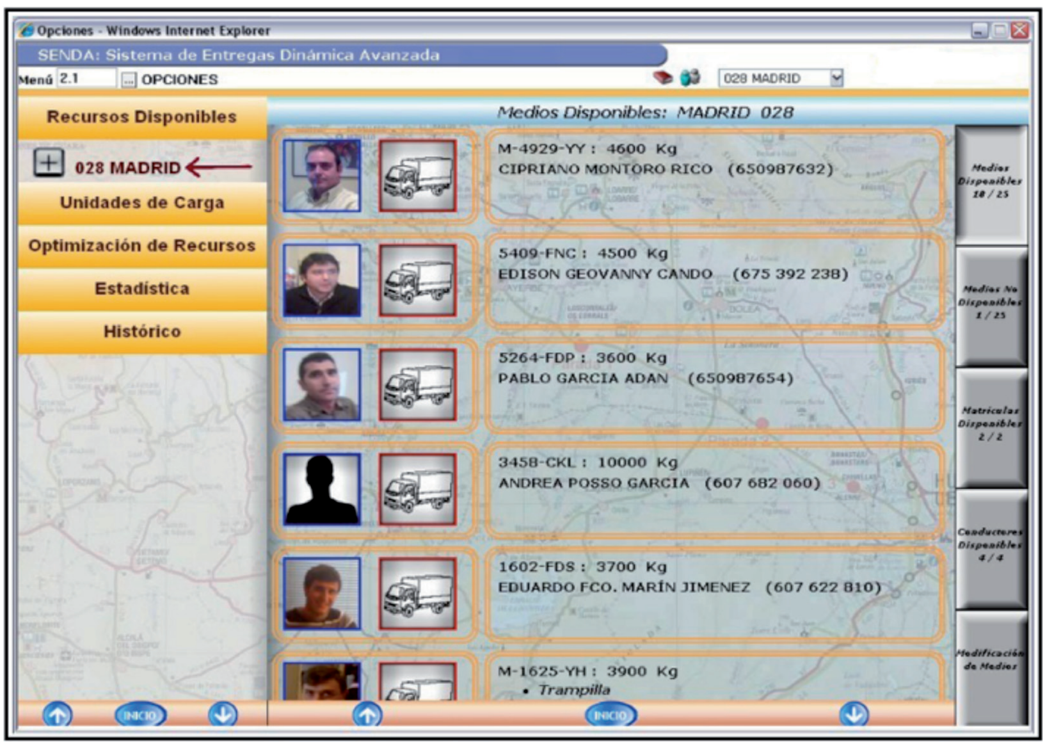

Fig. 4: Resources management window

to make queries on the DB with different criteria. The result that satisfies the search criteria appears at the center list with the main characteristics of all registers. If a register of the list is selected its detailed information is shown at the below part with the possibility of execute any of the different functions of edition.

The second section is made up of a set of different windows where information is displayed and the user interacts in different ways depending on the functionality provided. The routes optimization, the resources management and unforeseen events administration are dealt with here. Fig. 4 shows the first option of the menu, resources management. In this window, drivers are allocated to the set of vehicles. The system checks that matching is correctly performed by showing the main characteristics and constraints, (freight to transport, availability, holidays, breakdown of vehicles and so on).

Fig. 5 presents the second option of the menu, load units. In this window transport orders are classified according to their corresponding load type (normal, perishable, refrigerated, dangerous, etc). Each row shows grouped orders by load type with an illustration to easily identify the type and the most relevant data of the set of orders: name of the load type, weight, volume, number of orders and pickup/delivery nodes.

Clicking on any part of a row, it is possible to see orders that belong to each set (see Fig. 6). At the top of the window

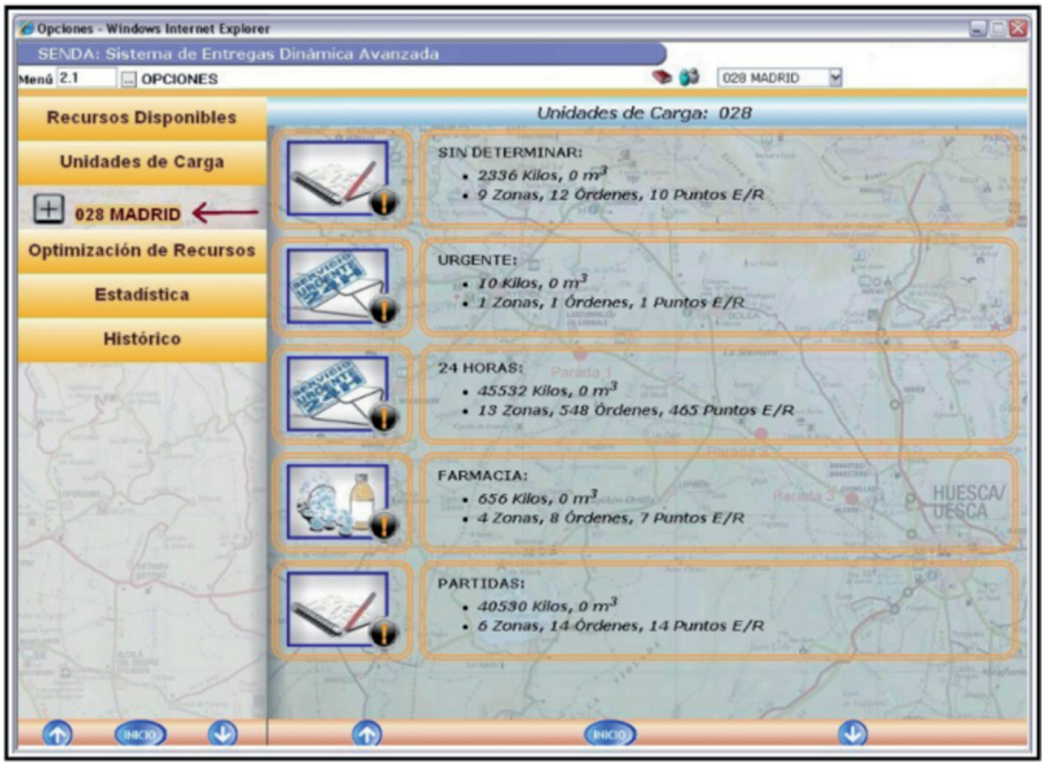

Fig. 5. Management window of load units

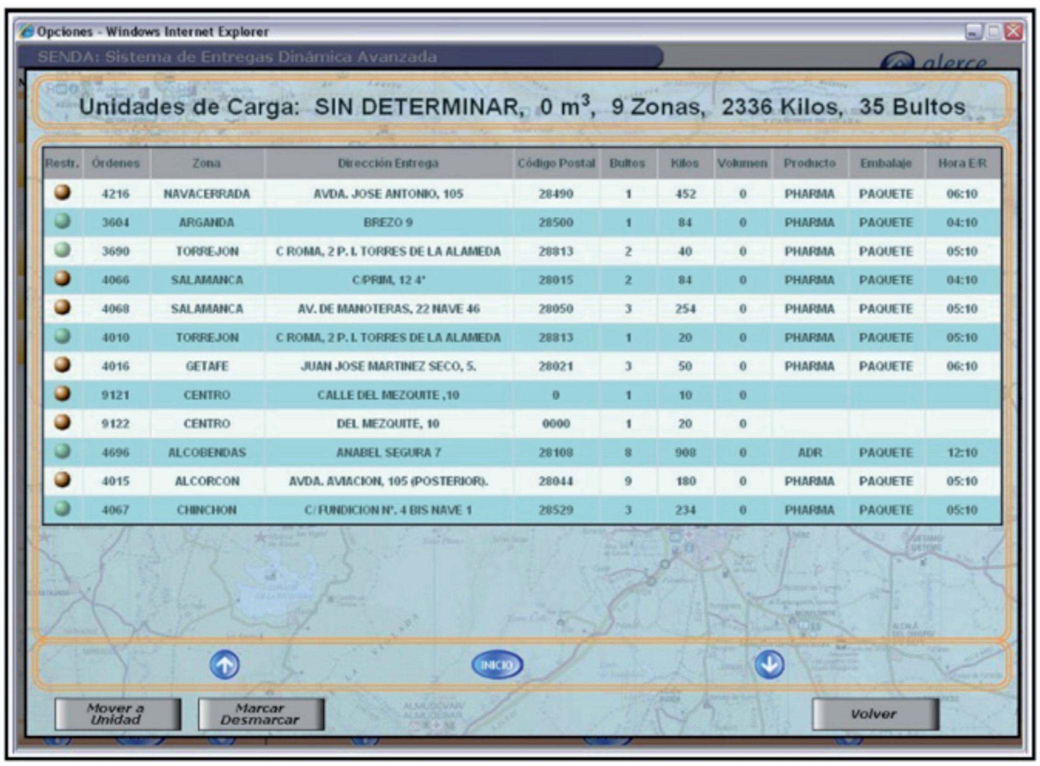

Fig. 6: Window with set of orders by load unit

the most relevant information about each order: order ID, address, zip code, weight, volume, pickup or delivery time, etc.

Fig. 7 presents the third option of the menu, optimization of resources where the allocation of daily orders to available resources is realized using the optimization algorithm.

On the left part, there are two pictures corresponding to the driver and to the vehicle. This pair of resources is responsible for undertaking the route. On the right part, there is a graph with two bars. The first represents the time dedicated to pickups and deliveries and the second reflects the percentage of the vehicle capacity filled. In the center of the window, the most important data of each route are shown: driver name, telephone, enrollment, vehicle capacity, number of pickups and deliveries and kilograms to distribute. At the bottom of the window there are eight buttons to realize several functions such as execute the calculation algorithm and modify generated routes by inserting and deleting orders.

If a route is selected by one click and then the bottom called 'Mapa' is clicked, the route is represented on a cartographic map (see Fig. 8). This representation is possible thanks to which offers a lot of functionalities. The route is shown with a specific

there appears a summary with the main characteristics of all the orders making up the selected set. The list below shows zoom level although the user can change this and see the route with more or less detail.

Fig. 7: Resource optimization window

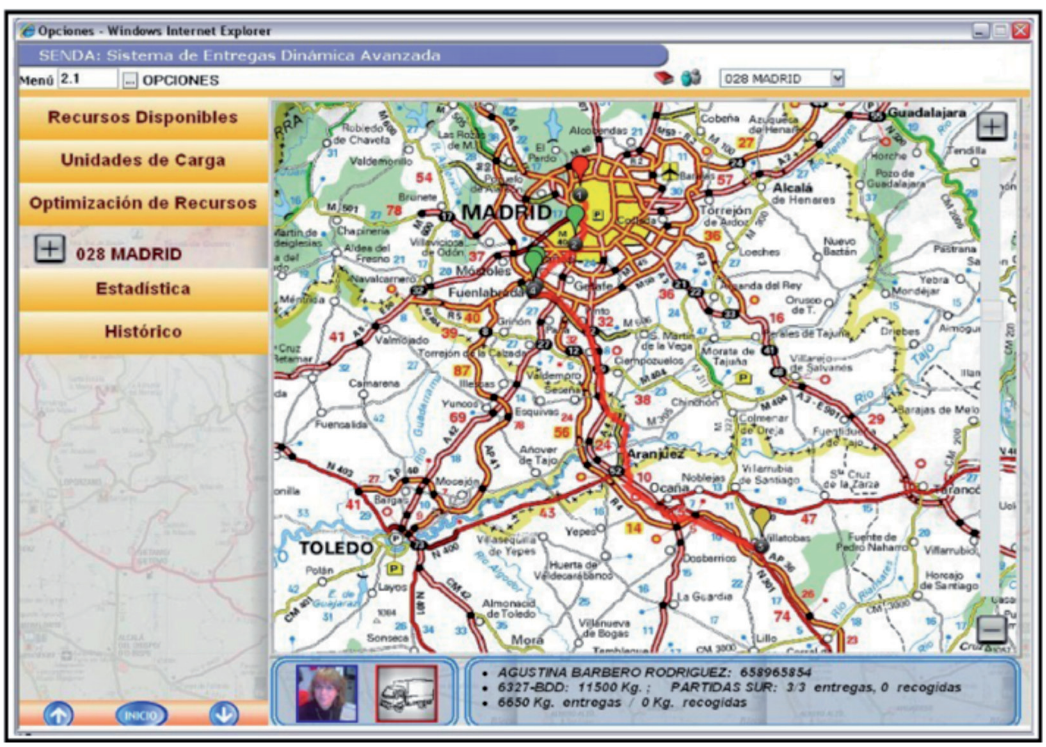

Fig. 8: Window of representation of a route on cartographic map

5. COMPUTATIONAL EXPERIMENTS

In order to evaluate the implemented algorithm, test problems have been generated from real cases experienced by a large transport company in Spain dedicated to the distribution on urban areas.

The generation of tests is defined by the number of orders, the number of available vehicles and the maximum number of orders to be transported by each vehicle. Both the service time as the time window of each order are imposed by the customer so they are independent and can not be modified.

The results of the experiments are listed in the Table I, obtained by multiple runs of the algorithm. The first four columns define the settings of the experiment. The rest of the columns measure the efficiency of all the solutions by means of two performance metrics, The total distance traveled ((Δ(d)) and the number of vehicles needed to transport the goods ((Δ(v)).

The computing time did not exceed 4 minutes in any case. The calculation of the algorithm was immediate with few orders. The results are shown for the route construction phase that obtains an initial feasible solution due to the quantity of constraints imposed and for the hybrid method.

For a small volume of orders, it can be seen that the construction method obtains the best solutions mainly due to the high number of constraints imposed on the problem initially. However, for large volumes the hybrid method encounters better solutions especially in terms of a reduction in vehicles used. For example, in the instance P38 the hybrid method reduces by 16% the distance respect to construction phase and uses 4 vehicles less.

It can also be appreciated that the algorithm initially uses the greatest number of available vehicles, mainly for few orders, since the construction method only reduces the available vehicles for 500 orders.

PBR	PED	VEH	MAX PED/VEH	CONSTRUCTOR		MÉTODO HÍBRIDO	
				$\Delta(d)$	$\Delta(v)$	$\Delta(d)$	$\Delta(v)$
P1	50	8	8	776.34	8	776.26	8
P2			10	785.15	8	785.08	8
P3			12	755.22	8	794.24	6
P4		9	8	841.05	9	840.97	9
P5			10	871.32	9	876.47	8
P6			12	835.8	9	847.15	7
P7		10	8	892.43	10	892.36	10
P8			10	918	10	944.61	8
P9			12	918	10	945.56	8
P11	100	14	8	1552.14	14	1466.64	14
P12			10	1497.62	14	1395.64	12
P13			12	1509.37	14	1452.43	12
P14		15	8	1594.31	15	1546.27	15
P15			10	1598.67	15	1493.21	12
P16			12	1613.3	15	1552.14	11
P17		16	8	1758.53	16	1714.83	16
P18			10	1698.94	16	1649.32	13
P19			12	1672.37	16	1635.46	15
P21	200	26	12	2995.92	26	2880.28	24
P22			16	2939.9	26	2834.27	25
P23			20	2937.52	26	2852.44	23
P24		27	12	3167.86	27	2944.53	26
P25			16	3164.66	27	2942.26	20
P26			20	3164.66	27	2935.87	21
P27		28	12	3293.72	28	3073.58	27
P28			16	3312.08	28	3055.36	27
P29			20	3312.08	28	3107.04	20
P31	500	64	12	4735.81	61	3990.26	57
P32			16	4780.48	61	3953.05	60
P33			20	4790.88	61	3908.25	60
P34		65	12	4715.73	62	3949.81	59
P35			16	4726.07	62	4056.05	59
P36			20	4706.99	62	4706.99	62
P37		66	12	4821.26	63	4100.81	59
P38			16	4889.89	63	4101.6	59
P39			20	4866.25	63	4001.04	61

Table I: Algorithm results of the test problems

6. CONCLUSIONS

This paper present a smart support system for urban freight distribution companies to manage and plan their routes of freight transport. The system is an innovative and intuitive application which allows an easy use of the system functionalities and may be easily adapted to specific case studies defined by the user.

The work has required a research-intensive stage to formulate the model of the problem as a combination of several well known problems of transport. All of them have been evaluated and integrated to configure a flexible stand-alone model using an algorithm based on metaheuristic techniques considering the characteristics found in the reality in order to reduce distribution costs and improve business efficiency.

This paper is the result of a research project with public funding in collaboration with a company that develops technology solutions to companies in the transport sector. Currently, the tool is being marketed by this company quite successfully.

Future research should be aimed at creating real-time routing solutions, a segment whose market penetration is still low. Newer tools are still emerging that reroute the routes when necessary. Nevertheless, more robust solutions are required that can automatically adapt real time traffic conditions to daily driver activities. It is necessary to implement approaches where groups of orders are considered as the first feasible solution but which can be modified by dynamic algorithms during the day as changes occur.

Another relevant point of interest is the usage of transportation forecasting tools in combination with transportation planning approaches. Due to changes in business conditions, freight capacity is expected to become constrained. This consideration is making users more effective in future operational planning. They are required to forecast more than five days ahead to allocate resources to transport operations. Most companies have adapted product forecasting systems, but these do not align well with transportation networks. Future DSS aimed at integrating forecasting with future planning are needed to offer robust transportation-specific allocation approaches that can provide clients and suppliers with predicted transport operations and route planning.

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