Improvement of Drug Delivery Routes Through the Adoption of Multi-Operator Evolutionary Algorithms and Intelligent Vans Capable of Reporting Real-Time Incidents

E. Onieva, E. Osaba, I. Angulo, A. Moreno, A. Bahillo, and A. Perallos

***Abstract*—An improved solution for drug distribution is presented in this paper. It is divided into two parts: i) a multi-operator evolutionary algorithm in charge of calculating the initial delivery routes and ii) an ambient intelligence-based support system able to tracing the merchandise along the distribution route. The first one establishes the routes to be followed by the vehicles, based on a proposal of estimation of the travel times. The second one is formed by a system able to recognize and trace the drugs inside each vehicle. A laboratory experimentation has been conducted in order to demonstrate the adequacy of the route calculator. In addition, a field experimentation has been carried out by implementing the traceability system in a delivery van which of the drug distributor in the city of Bilbao.**

***Note to Practitioners*—Motivated by the specific needs found by a drug distributor in managing deliveries to pharmacies involved in its supply chain, this paper considers an optimization problem as the proper way to model the particularities found in this scenario. This paper proposes the use of a combinatorial optimization problem as the way to model problems. Due to the fact that distributor's clients are located in different cities, the proposal considers travel times both between cities and inside the city. In addition, rush hours are also taken into account, in order to provide a more realistic model. Finally, a radio frequency identification-based solution is proposed, in order to implement traceability in the delivered products, as well as to prevent human errors. Additionally, in case an unavoidable error occurs, the solution offers also an incident management mechanism.**

***Index Terms*—Intelligent transportation systems, mobile information systems, traceability, radio frequency identification (RFID), supply chain management, combinatorial optimization, genetic algorithms.**

Manuscript received July 07, 2015; accepted August 24, 2015. This paper was recommended for publication by Associate Editor H. Hu and Editor M. P. Fanti upon evaluation of the reviewers' comments. This work was supported in part by the Spanish Ministry of Science and Innovation through the TRAZAMED: Plataforma integral basada en tecnologías de identificación RFID y Datamatrix para la trazabilidad de medicamentos project, and in part by the Projects TEC2013-45585-C2-2-R and RTC-2014-3061-4 from the Spanish Ministry of Economy and Competitiveness.

The authors are with the Deusto Institute of Technology (DeustoTech), University of Deusto, Bilbao 48007, Spain (e-mail: enrique.onieva@deusto.es; e.osaba@deusto.es; ignacio.angulo@deusto.es; asier.moreno@deusto.es; alfonso.bahillo@deusto.es; perallos@deusto.es).

This paper has supplementary downloadable multimedia material available at http://ieeexplore.ieee.org provided by the authors. The Supplementary Material shows instances of the dynamic asymmetric capacitated vehicle routing problem with variable service and travel times (DAC-VRP-VSTT) presented in the work: Improvement of Drug Delivery Routes Through the Adoption of Multi-Operator Evolutionary Algorithms and Intelligent Vans Capable of Reporting Real-Time Incidents. This material is 0.69 MB in size.

Digital Object Identifier 10.1109/TASE.2015.2476508

I. Introduction

DRUG distribution presents particular challenges. Due to the intense competition between distributors, high quality of service is required. Since it is a market where most competitors offer similar products and prices, service quality is a key factor. Thereby, significant delays or wrong deliveries can end in the loss of a client [1]. In this way, a traceability system can be described as *the documented identification of the operations which leads to the production and sale of a product* [2]. The opportunity of connecting traceability with the whole documentation and control system is an effective means of boosting the consumer perception of quality [3].

From the perspectives of economics and health, the pharmaceutical drug supply chain must be controlled at every stage: from the production phases in the laboratory until the products reach the pharmacies where they are sold to the public [4]. These requirements are reflected by the Spanish Ministry of Health and Consumption through the new Royal Decree on drug traceability, developed in accordance with Directive 2003/94/EC of the European Commission [5]. Moreover, the added costs are hardly permissible in an industry where profit margins use to be set by administrations [6].

Due to the demanded quality requirement, it is essential to deploy systems that meets the new regulations, while maintain a high quality of service and not complicating the tasks of the carriers [7], e.g., the installation of a system that needs the use of hardware, such as handheld radio frequency identification (RFID) [8], [9] readers or similar devices, cannot be considered a solution because they add new tasks.

Numerous studies have been focused on monitoring the drugs distribution during the last decades [10], [11]. More recently, in [12], both the technical and business related adaptations involved in the transformation toward a RFID-aided drugs supply chain are analyzed. In [13], it is discussed about how RFID can be applied to increase the integrity and confidence in the pharmaceutical supply chain. In [14], it is stated that the lack of system-level design methodologies was one of the main obstacles to adopt wireless sensor network (WSN) or RFID systems in industries.

This paper is organized as follows. Section II details the contributions proposed in the present work. Section III presents the mathematical model used to mimic the scenario faced by a distributor, and proposes a metaheuristic to optimize routes. Section IV describes the deployed ambient intelligence (AmI) environment, based on an intelligent van. The comparative experimentation of the routing metaheuristic is presented in Section V. The validation of the developed traceability system implanted in a real warehouse is presented in Section VI. Finally, some concluding remarks are stated in Section VII.

II. Contribution of the Work

A solution designed to adapt the drug distributor to the new regulatory (and more competitive) environment, without altering the behavior of the workers is provided. First, the specific distribution problem is modeled as a rich version of the vehicle routing problem [15], considering all the restrictions managed by the drug distributor, as well as the state of the traffic. Then, an in-house system based on evolutionary algorithms [16] for a better route scheduling is deployed. The method integrates the adaptation of the crossover probability with the capability of selecting the crossover operator depending on the state of the execution. Second, an onboard system mounted in delivery vans collects the required data for traceability without human interaction, by using an embedded RFID system [17], [18]. Furthermore, this last system is responsible for real-time incident detection and notification to the carrier.

The main value of the proposed approach resides in the absence of human intervention during the delivery. The deployed system autonomously monitors the state of the transported deliveries, as well as matches the location of the van with the destination of the goods. It checks for the occurrence of deviations in the original plan in real time, and informs to the carrier by his cellphone, thus eliminating the need of using additional equipment by the carrier. In addition, the route is initially calculated by an evolutionary algorithm that takes into account the different travel times for normal and rush hours. Finally, routes are automatically adapted in case a deviation in the delivery plan is detected. These deviations are solved with consideration in the priority of each particular delivery.

In order to test the proposal, a method to estimate travel times in the locations near to the city of Bilbao is presented, using its results to build a test set composed of seven instances that are tested under three different capacities of the distribution van. In the end, the result is an implementation of a smart environment combining in-house expert systems with wireless scenarios and with a flexible system architecture to support real-time monitoring and interaction [19]. Thus, it depicts a successful experience of using artificial intelligence algorithms in combination with AmI environments in order to resolve a real logistic problem [20].

III. Proposed Routing Problem and Solver

Route scheduling is an important process in the field of logistics. For most environments, the travel time is the most relevant criterion when planning a route. This section proposes a specific variant of the vehicle routing problem (VRP) in which travel times along destinations are calculated considering the cities in which they are located, as well as the hour of the day. In addition, a scheduler based on evolutionary algorithms with multiple crossover operator and adaptive crossover probabilities is designed to plan the route to be followed by the fleet of vans.

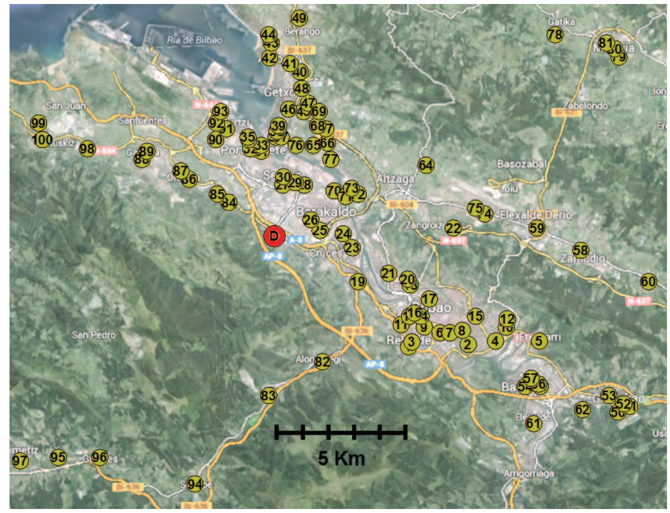

Fig. 1. An aerial view of Bilbao's surroundings, showing the locations of the 100 pharmacies considered in this work.

A. Description of the Problem

Considering the problem of a drug distribution company, a test set consisting of 100 pharmacies and a depot has been developed. The locations of selected pharmacies in the surroundings of Bilbao, Spain, are represented by their latitude and longitude.[1] The pharmacies are distributed in 31 different cities, Fig. 1 shows their distribution, and the depot is marked with a D.

All the vehicles are supposed to have the same capacity, which is varied in the experimentation (Section V-A). Vehicles initiate their routes at 8:00 am. To better fit the real world, travel times between two given pharmacies i and j are calculated in two ways: t_{ij}^r, which denotes the travel time during rush hours (between 8:00 am and 10:00 am and between 1:00 pm and 3:00 pm), while t_{ij}^n indicates the travel time during the rest of the day. This distinction is made since it is assumed that is more costly to travel between two points at rush hours, where traffic volume is higher.

Each pharmacy has an associated service time, which also varies depending on the hour of the day. In this case, it is assumed that the rush hour is when there is a greater influx of people. s_i^r depicts the service time of pharmacy i in influx rush hour, which is between 10:00 am and 12:00 pm. The rest of the day time service is represented by s_i^n. In this way, the following attributes are established for each pharmacy i:

$$\begin{aligned}
&\text{Demand}_i = 1, \quad \forall i \in \{1,3,5,7,\ldots,99\}\\
&\text{Demand}_i = 2, \quad \forall i \in \{2,4,6,8,\ldots,100\}\\
&\{s_i^n = 300s,\ s_i^r = 500s\}, \quad \forall i \in \{1,2,5,6,\ldots,97,98\}\\
&\{s_i^n = 600s,\ s_i^r = 800s\}, \quad \forall i \in \{3,4,7,8,\ldots,99,100\}
\end{aligned}$$

[1]Taken from *http://maps.google.com* (accessed in June 2015).

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where Demand_i represents the number of containers needed for transporting the delivery to the pharmacy i.

Furthermore, for a greater adaptability to the real world, the problem presented in this paper considers a dynamic situation. This dynamism will cause route replanning. This feature is detailed in Section III-A2. Before that, Section III-A1 explains the calculation of the travel times between pharmacies.

1) Travel Time Calculation: Pharmacies are clustered according to the cities in which they are located. In addition, there is a circular *frontier* defined, with center calculated as the average position of the pharmacies in the city and radius calculated as the longest distance from the center to a pharmacy in the city plus a threshold (in this case of 200 m).

In order to calculate travel times between pharmacies, it is assumed that the Euclidean distance $d(i, j)$ between two pharmacies can be traveled at six different speeds

$$\begin{aligned} V^{n|r}_{\text{closer}} &= \{35, 25\} \text{ km/h} \\ V^{n|r}_{\text{away}} &= \{40, 30\} \text{ km/h} \\ V^{n|r}_{\text{highway}} &= \{75, 50\} \text{ km/h} \end{aligned}$$

where the subscripts closer and away denote the speed used to approach/leave the center of the city, and highway represents the speed used in travels between cities. The superscript n or r denote that the trip is done during normal/rush hours. To define the speeds, it has been supposed that: i) at rush hours, speeds are lower; ii) to get closer to the city center is slower than to leave the city, and iii) to move between cities is faster than to move inside the city. Thus, the time to move between two pharmacies i and j is calculated in three different ways, depending on their locations.

If both pharmacies are in the same city, and assuming pharmacy i is nearer to the city center than pharmacy j, travel times are calculated, as shown in (1) and (2)

$$t^{n|r}_{ij} = d(i, j)/V^{n|r}_{\text{away}} \quad (1)$$
$$t^{n|r}_{ji} = d(j, i)/V^{n|r}_{\text{closer}}. \quad (2)$$

If both pharmacies are in different cities, the line that joins them is divided into three pieces with lengths $d(i, F_i)$, $d(F_i, F_j)$, and $d(F_j, j)$, the first denotes the distance between the pharmacy i and the frontier F_i of its city, the second, the distance between the two relevant frontiers F_i and F_j, and the third, the distance between the pharmacy j and F_j. With this, travel times between any two pharmacies in different cities are calculated, as presented in (3) and (4)

$$t^{n|r}_{ij} = \frac{d(i, F_i)}{V^{n|r}_{\text{away}}} + \frac{d(F_i, F_j)}{V^{n|r}_{\text{highway}}} + \frac{d(j, F_j)}{V^{n|r}_{\text{closer}}} \quad (3)$$
$$t^{n|r}_{ji} = \frac{d(j, F_j)}{V^{n|r}_{\text{away}}} + \frac{d(F_i, F_j)}{V^{n|r}_{\text{highway}}} + \frac{d(i, F_i)}{V^{n|r}_{\text{closer}}}. \quad (4)$$

The third case is where the pharmacies are located in different cities, but they overlap. In this case, the arc is divided into two pieces with lengths $d(i, F_i)$ and $d(F_i, j)$. The travel times are calculated as in (5) and (6)

$$t^{n|r}_{ij} = \frac{d(i, F_i)}{V^{n|r}_{\text{away}}} + \frac{d(F_i, j)}{V^{n|r}_{\text{closer}}} \quad (5)$$
$$t^{n|r}_{ji} = \frac{d(j, F_j)}{V^{n|r}_{\text{away}}} + \frac{d(F_j, i)}{V^{n|r}_{\text{closer}}}. \quad (6)$$

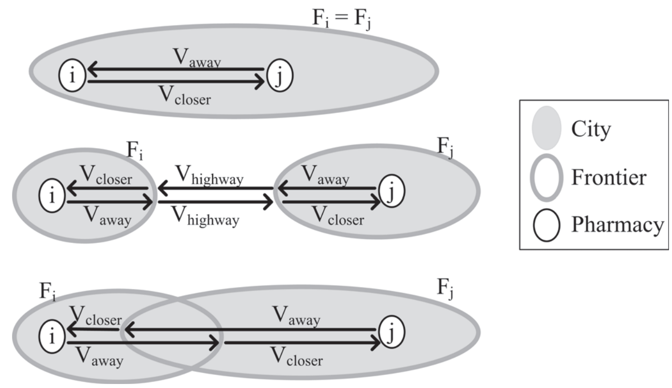

Fig. 2. Graphical example of speeds used to cover the distance between two pharmacies: in the same city (top), in different cities (center), in different and overlapping cities.

Fig. 2 represents graphically the situations considered to calculate the travel time. It is important to note that the speeds used in (1) to (6) are different depending for normal or rush (superscript n or r) hours.

2) Incidence Management: Bringing dynamism to routing problems is a relatively new practice which many researchers have emphasized in recent years [21]. Dynamism makes necessary to modify or reschedule the pre-planned routes, either because of an incident or the arrival of new information that was not present at the beginning of the scheduling. The significance of dynamism is highlighted by the wide variety of environments in which it can be applied, and it can be modeled in many different ways.

In the present case, the dynamism introduced by an incident occurs in case a delivery for a pharmacy has suffered a problem, e.g., an incomplete delivery. In such a case, the system has to react to this incident, and the affected route has to be rescheduled in order to complete the service. It is assumed that pharmacies must be revisited by the same vehicle that made the first delivery, since this vehicle is the only one that has the products needed to complete the initial order.

The replanning of the route is made as a function of a priority parameter (Prio_i), assigned to each pharmacy. Prio_i can take values high (H) and low (L). In the first scenario, at the time the notification of Inc^t_i is received, the route has to be modified, giving priority to supply i. On the other hand, if i has $\text{Prio}_i = L$, the route is modified by reinserting i in a place that involves a smaller increase in the cost of the route.

A visual example of this priority management is shown in Fig. 3, where the initial route $\{1, 2, 3, 4, 5, 6\}$ is shown; and it is supposed that, when the vehicle is on the way between the clients 3 and 4, a notification Inc^t_2 arrives. Assuming that

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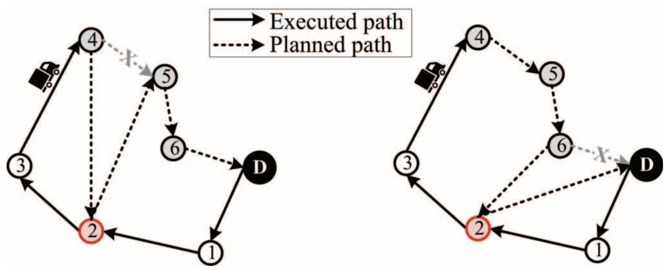

Fig. 3. Example of high (left) and low (right) priority incident treatment. Incidence in location 2 is supposed to appear when vehicle is between locations 3 and 4.

$\mathrm{Prio}_2 = H$, the system reacts by giving priority to supplying 2. Thus, the remainder of the route is modified to $\{4, 2, 5, 6\}$ [Fig. 3, (left)]. In case that $\mathrm{Prio}_2 = L$, the remainder of the route is changed to $\{4, 5, 6, 2\}$ [Fig. 3, (right)].

Finally, Prio_i is established as follows in the presented problem:

$$\mathrm{Prio}_i = L, \forall i \in \{[1 \to 4], [9 \to 12], \ldots, [93 \to 96]\}$$
$$\mathrm{Prio}_i = H, \forall i \in \{[5 \to 8], [13 \to 16], \ldots, [97 \to 100]\}.$$

Furthermore, the incident Inc_i^t has two parameters, i, which is the affected pharmacy, and t, which represents the time (in seconds) that elapses between the vehicle's arrival at i and the arrival of the notification.

3) Summary: With all the considerations made in the previous sections, it is important to note that, in this paper, a rich model of the classical VRP has been considered. It includes the following aspects.

- Variable travel times: The travel time between two pharmacies is different in rush and normal hours. This increase the complexity of the problem, bringing originality to the problem. Few are the occasions at which it has been treated [22], [23].
- Variable service times: Pharmacies have two different service times, depending on the time of the day. As in the above feature, this gives originality and complexity to the model.
- Asymmetry: Costs related with arcs are asymmetric. This feature adds complexity and realism to the problem [24].
- Dynamism: As explained in Section III-A2, the model provides dynamism to the problem.

With all this, in this paper, a variant of the VRP called dynamic asymmetric capacitated VRP with variable service and travel times (DAC-VRP-VSTT) is presented and tested. The objective of the problem is to find a set of routes which minimizes the total time needed and satisfies the following conditions: i) all the pharmacies have to be visited once and only once (dynamism apart); ii) all the routes have to start and finish at the depot; iii) the vehicle capacity must be respected; and iv) all incidents must be resolved. In a formal way, the objective function (to be minimized) is presented in (7)

$$\text{fitness} = \sum_{i,j \in N} \left(x_{ij}^n \cdot t_{ij}^n + x_{ij}^r \cdot t_{ij}^r\right) + \sum_{i \in N} \left(y_i^n \cdot s_i^n + y_i^r \cdot s_i^r\right) \quad (7)$$

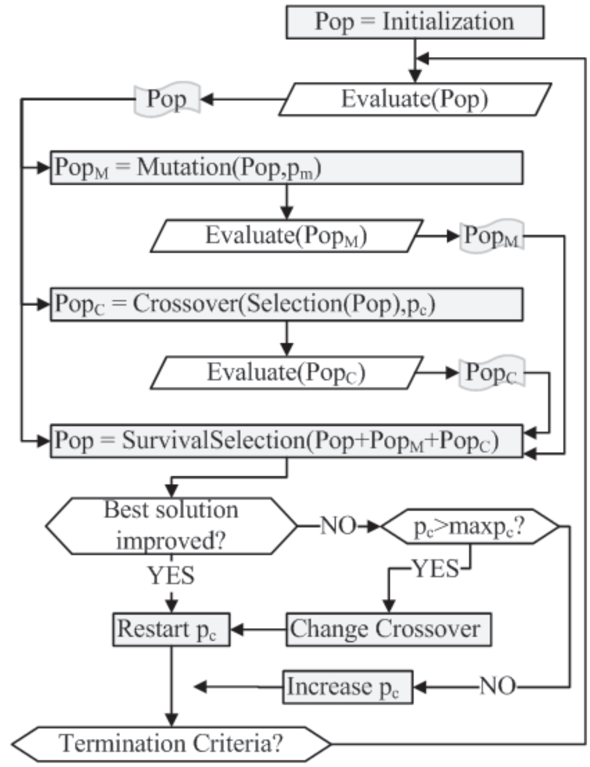

Fig. 4. Flowchart of the proposed AMCEA.

where the first summation calculates the travel time needed for completing the route, while the second one measures the total service time spent. In particular, t_{ij}^n and t_{ij}^r denote the travel time between nodes i and j in normal and rush hours, respectively; and s_i^n and s_i^r denote the service time for the node i, depending of the hour. On the other hand, x_{ij}^n, x_{ij}^r, y_i^n, and y_i^r are binary variables denoting if a certain arc/node is used in the solution in normal or rush hours.

B. Proposed Technique for the DAC-VRP-VSTT

Dynamic versions of variants of routing problems have been faced before in the literature, many of them by the use of Ant Colony Optimization (ACO) algorithms [25], [26]. Given the flexibility demonstrated by evolutionary algorithms when incorporating new features and restrictions to the problem, as well as taking into consideration that the algorithm is applied to a real environment for the distribution of goods to pharmacies, it was opted for a technique which would be simple to implement and quick to execute. The metaheuristic used is an Adaptive Multi-Crossover Evolutionary Algorithm (AMCEA). This algorithm was first introduced in [27], proving to be a competitive alternative to solve routing problems, such as the traveling salesman problem, the capacitated vehicle routing problem, vehicle routing with backhauls and multi-depot vehicle routing problem.

The proposed AMCEA is a variant of the classic Genetic Algorithm (GA) [28]. Fig. 4 presents its flowchart. The main loop starts with a population (Pop), which is used by the crossover and mutation operators in a parallel way in order to generate Pop_C and Pop_M, respectively (considering probabilities of such operators, p_c and p_m). The new population is constructed by joining the three populations and using a survival function. After that, p_c is restarted/increased and the current crossover operator is changed depending on the performance of the evaluation. Some remarks about its operating properties are as follows.

- AMCEA is expected to start with a very low or null value for the crossover probability p_c and a high value for the mutation probability p_m.
- Instead of relying on the population fitness, as most previous studies [29], [30], the proposed technique adapts p_c depending on the current generation number and the search performance in recent iterations.
- The proposed algorithm combines the p_c adaptation and the multi-crossover mechanism.

Regarding the adaptive mechanism, p_c if modified every generation, depending on the results obtained in the previous one. If the best solution found by the technique has been improved in the last generation, p_c is restarted from 0. Otherwise, p_c increases based on the following (8):

$$p_c = p_c + \frac{2 \cdot G_{wi} + G}{N_I^3} \tag{8}$$

where G_{wi} is the number of generations executed without improvements, G is the total number of generations executed, and N_I is the number of individuals in the population.

In relation to the multi-crossover feature, the proposed AMCEA uses more than one crossover operator, which are alternated during the execution. At the beginning, one operator is assigned at random and it is randomly replaced by another one when necessary, allowing repetitions. For this purpose, a maximum p_c value is defined: maxp_c. If over the generations p_c exceeds maxp_c, the crossover function is replaced at random by another one, and p_c is restarted with the initial value.

1) Encoding and Operators: For the proposed DAC-VRP-VSTT, individuals have been encoded using an adaptation of the path representation [31]. In this case, solutions are represented as a permutation of nodes, separating different routes by zeros. For example, a solution with three routes, for instance $\{2,5,7\}$, $\{1,8,6\}$ and $\{4,3,9\}$, is encoded as: $\{2,5,7,\mathbf{0},1,8,6,\mathbf{0},4,3,9\}$. This encoding has been previously used in the literature for the VRP and its variants [32], [33].

The crossover functions used for the proposed AMCEA are the short routes (SR), the random routes (RR), and the large routes (LR) crossovers. With the SR, first, the shortest 50% of the routes in one randomly chosen parent are selected and inserted in the child. Then, the nodes already inserted are removed from the other parent. Finally, the remaining nodes are inserted in the same order in the final solution, creating new routes. The RR works similarly to the SR. In this case, in the first step, the routes selected from one of the parents are chosen randomly, instead of selecting the shortest ones. Ultimately, in LR, the longest 50% of the routes of one randomly selected parent are selected.

The mutation function used is an adaption of the classic insertion mutation [34], which is called Vertex Insertion Routes. This function selects and extracts one random node from a random route. Then, the node is inserted at a random position in another randomly selected route. New route creation is possible with this function.

Finally, a binary tournament operator is used to select parents to be crossed. In addition, a half elitist—half random function (without repetitions) has been developed as survival function. First, the $0.5 \cdot N_I$ best individuals from $(\mathrm{Pop} \cup \mathrm{Pop}_M \cup \mathrm{Pop}_C)$ survive into the next generation. The remaining $0.5 \cdot N_I$ individuals are randomly selected from the not used in $(\mathrm{Pop}_M \cup \mathrm{Pop}_C)$. This mechanism guarantees that, in the case all the best individuals belong to the current population, elitism of 50% is performed. To balance this possibility of high elitism (and short stagnation time) with diversification of the population, the other 50% of the new population is randomly chosen among resulting individuals from crossover and mutation operators.

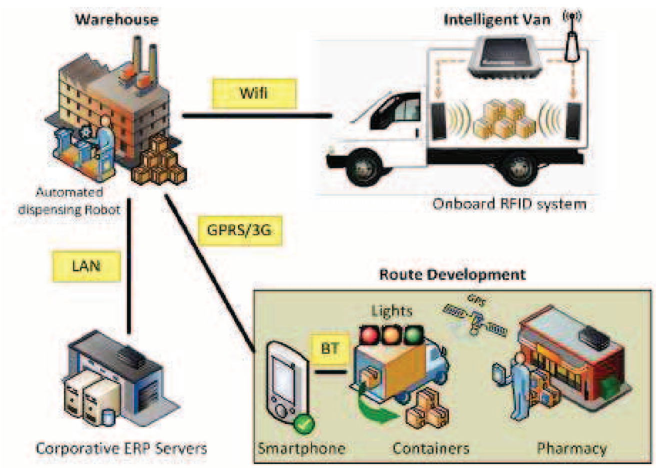

Fig. 5. Agents and their interactions in the drug distribution chain, as well as the communication protocol used in each interaction.

IV. Proposed Intelligent Van for Real-Time Incident Reporting

One of the critical characteristic of the proposed system is the possibility of allowing incident reporting in real time. In order to achieve this goal, this section presents the incorporation of RFID technology in pharmaceutical drug distribution. Section IV-A justifies the use of the RFID technology, and presents the overall working of the system. Subsequently, Section IV-B gives the details of the characteristics of the AmI system implemented.

A. The Adoption of RFID Technology in the Drug Distribution Scenario

Once the destination of each container is known, dispense robots organize all requested products in containers ready to be loaded into distribution vans. Passive transponders are attached to containers so their electronic product code (EPC) is related to drugs inside each container and its destination.

Fig. 5 shows the interactions between the main agents in the distribution chain. When the delivery van arrives at the warehouse, its onboard system is connected to the office via Wi-Fi in order to download the needed information about the route to take, calculated as presented in Section III-B.

Once vans start being loaded, an RFID reader module located inside the van detects each container that enters or leaves the van. The RFID module detects the transponders' EPCs and sends them to the onboard system. In case of a mistake in loading or unloading a container, a red light is switched on in the trunk, indicating that there is a problem.

Since all drivers carry a smartphone, an application (Section IV-B3) informs them via Bluetooth. The driver can try to solve the mistake. If this is not possible, the application sends a report to the manager. In addition, in case the route needs to be modified, the method proposed in Section III-A2 is applied. If the process is done as planned, the driver does not need to use the application, thus simplifying its use.

The driver starts the route once the cargo is loaded. The van knows its location using global position system (GPS) technology. When the van stops and its door is opened, the system detects the nearest pharmacy in the route. It checks for the unloaded containers and switches on a green light when all the desired containers have left the van (i.e., it senses that the corresponding RFID tags are not present). In case the green light remains off, the carrier has to use the mobile application to check the cause of the problem. If there is any unsolvable problem, the carrier can continue the route and the system reports the incident to the manager.

It is important to note that this is a non-intrusive system, and the carrier does not need to register loads or unloads. In this way, the carrier can work in the usual way, not realizing that the system monitors each event and notifies the warehouse only in case of an error.

The system also stores the location of the van and EPCs of containers loaded at regular intervals. Once the van returns to the warehouse, the system sends an XML file through File Transfer Protocol (FTP) containing the information stored during the route.

B. Implementation of the Ambient Intelligence (AmI) System

The core of the AmI system is given by the intelligent van in which an onboard system is installed. A specific middleware for communication has been developed to connect the system with the rest of the modules that compose the system architecture.

The implemented architecture can be decomposed into four different parts: i) the onboard system itself; ii) the cargo identification system; iii) the mobile application; and iv) the control software solution. Next, each module is described from a functional and technical point of view. Fig. 6 shows interactions between elements in the architecture, for a more detailed description, refer to [17].

1) Onboard System: The system is implemented in an ISEE IGEPv2 MPU platform based on a DM3730, this is a system on a chip that integrates a 1 GHz ARM Cortex-A8 Core. This is a small sized card ($93 \times 65 \times 15$ mm) containing the communication resources needed. The platform runs under a Linaro distribution including Wi-Fi communication for updating information at the warehouse and Bluetooth for communicating with the mobile application. The platform has global purpose input/ouput pins, used to activate the lights and to detect when the van doors are opened.

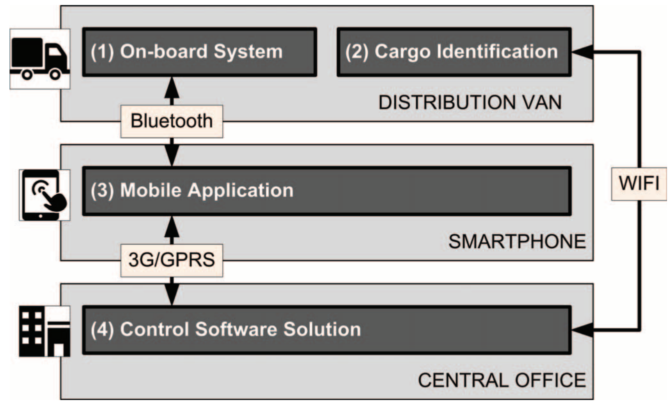

Fig. 6. Diagram of the system architecture and communications among the different subsystems.

Furthermore, the board has serial ports, used for communication with the RFID reader and the GPS receiver. Finally, the platform has an SD card to store the acquired data. The onboard system is powered by an independent battery, charged from the supply system of the van.

2) Cargo Identification System: The system is able to determine the place where the containers have been left, supported by the GPS. The attachment of a passive tag to containers makes the investment affordable, while allows the system to know containers that enter or leave the van.

With respect to the RFID tags, Confidex's Carrier Tough (Fig. 9) tag was chosen to be attached to containers. Tags work using EPC Gen2 Class1 protocol, with frequency 860–960 MHz, and its reading range is 4–6 m (enough for a van).

The RFID reader located in each van has RS-232 communication with the embedded device and wireless communication with the passive transponders. A ThingMagic's Mercury5e-EU RFID Reader[2] has been used, operating at the UHF frequency range to improve the interrogation distance, and bears the EPC Gen2 protocol, which is more robust against noise and interferences. It has 30 dB read gain within the range of 865.6–867.6 MHz. With an antenna of at least 6 dBi, it can read tags at 9 m within its nominal sensitivity of -65 dBm.

3) Mobile Application: The use of a mobile device supports the driver with information offered in a more direct way [35], maintaining the level of non-intrusiveness [36]. In this way, a multiplatform application that works on most of the existing smartphones (Android, Apple, BlackBerry) has been implemented. Fig. 7 shows the interface of the implemented mobile application, which supports:

- Management of incidents and report to the drive and control center in an automatic way.
- Navigation aid to the driver during the route.
- Bluetooth communication with the RFID reader to detect deviations in the original plan.

4) Control Software Solution: This relates to an application for monitoring drug traceability, schedule optimized routes, and locate vehicles of the fleet. The developed control panel

[2]Accessed on 2014: *http://www.thingmagic.com/embedded-rfid-readers/mercury5e/1-embedded-rfid-readers/3-mercury5e*

This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination.

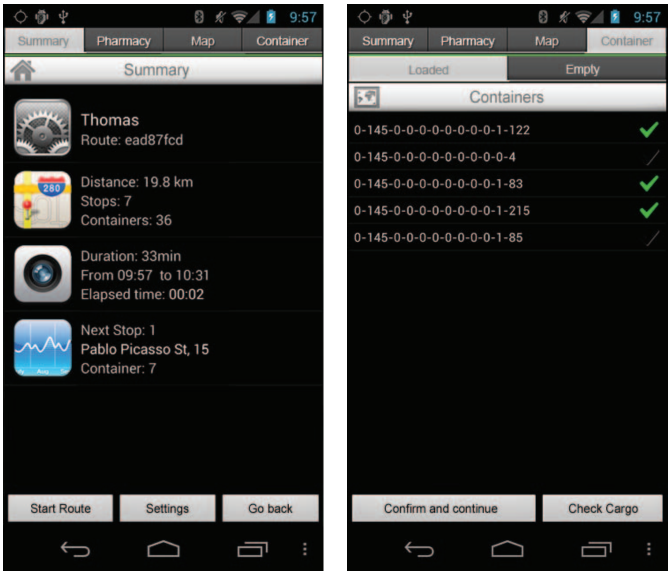

Fig. 7. Screenshots of the developed mobile application. Delivery's summary (left) and codes regarding containers inside the vehicle (right).

Fig. 8. Screenshot of the web interface of the solution displayed.

includes: i) product traceability; ii) fleet management; and iii) optimized schedules (Section III).

The control panel is based on the ASP.NET development framework and has been implemented making use of JavaScript, CSS3, HTML5, Ajax, and jQuery, using also tools offered by *Google* for displaying geographical information. Fig. 8 shows a screenshot of the solution, which displays the planned routes, actual position of vehicles, and location of the containers.

V. Experimentation With the Routing Algorithm

This section describes the conducted experimentation with the routing process, which consists in applying the designed AMCEA (Section III-B) to the proposed DAC-VRP-VSTT (Section III-A). In order to increase the reproducibility, the procedure to generate instances used in this experimentation is detailed in Section V-A. This section finalizes by presenting the obtained results (Section V-B).

A. Details of the Experimentation

In the experimentation, the outcomes obtained by the proposed AMCEA have been compared with the ones obtained by three different classical GAs. Each GA has the same parameters, and the only difference between them is the crossover function employed. An initial population of $N_I = 75$ randomly generated individuals is used for all the algorithms. The p_c of every GA is 100%, and the p_m has been set at 10%. Elitism is performed by keeping always a copy of the best individual found in the next generation. For the AMCEA, the p_m has been established in 100%, which means that the mutation is applied to all individuals. The initial p_c has been set at 0%. Along the execution, this p_c evolves in accordance with (8). In addition, maxp_c has been established at 50%. Finally, the execution of every technique finishes when there are $n/2 + \sum_{k=1}^{n/2} k$ generations without improvements in the best solution, where n is the size of the problem (number of nodes).

As reproductive operators, functions explained in Section III-B1 have been used for the different GAs. All of them use the insertion function as mutation operator. In this way, the three GAs are defined as GA_{SR}, GA_{RR} and GA_{LR}, depending on the crossover function used.

In order to carry out a proper experimentation, apart from using the instance presented in Section III-A, with 100 pharmacies (Pharmacies100 from now), another six instances have been generated using subsets of 50 and 75 pharmacies[3]

$$\begin{aligned}
\text{Pharmacies75}A &= \text{Pharmacies100} - \{1, 5, 9, \ldots\} \\
\text{Pharmacies75}B &= \text{Pharmacies100} - \{2, 6, 10, \ldots\} \\
\text{Pharmacies75}C &= \text{Pharmacies100} - \{3, 7, 11, \ldots\} \\
\text{Pharmacies75}D &= \text{Pharmacies100} - \{4, 8, 12, \ldots\} \\
\text{Pharmacies50}A &= \text{Pharmacies100} - \{1, 3, 5, \ldots\} \\
\text{Pharmacies50}B &= \text{Pharmacies100} - \{2, 4, 6, \ldots\}.
\end{aligned}$$

Each instance has been executed assuming three different capacities for the vehicles ($Q = \{10, 20, 30\}$), measured in the number of containers that they can transport.

B. Results

The tests have been performed on an Intel Core i5 2410 laptop, with 2.30 GHz and a 4 GB of RAM. JAVA was used as the programming language. Each experiment was repeated 30 times. The outcomes are shown in Table I. For each algorithm, average and standard deviation of obtained fitness, calculated as presented in (7), are displayed, as well as the computational time. The best result found for each one of the instances is also displayed. It is noteworthy that the AMCEA is the technique which reported all the best found solutions. All the values shown (with exception of N_V) are expressed in seconds.

The results depicted from this experimentation lead to the conclusion that the proposed AMCEA outperforms the implemented GAs, both in terms of result quality and runtimes. Anyway, it cannot be assumed that they are the optimal solutions.

[3]Instances used in this work can be downloaded in: *http://research.mobility.deustotech.eu/media/publication_resources/Instances_Onieva_IEEE-ASE2015.zip*

TABLE I
RESULTS OF *AMCEA*, GA_{SR}, GA_{RR}, AND GA_{LR} FOR THE DAC-VRP-VSTT. FOR EACH INSTANCE, THE AVERAGE AND STANDARD DEVIATION OF FITNESS (SECONDS), AS WELL AS THE AVERAGE EXECUTION TIME (SECONDS) ARE SHOWN. IN ADDITION, FITNESS OF THE BEST SOLUTIONS FOUND (SECONDS) AND THEIR NUMBER OF VEHICLES ARE PRESENTED

		AMCEA			GA_{SR}			GA_{RR}			GA_{LR}			Best Found	
Instance	Q	Avg	dev.	time	Avg.	dev.	time	Avg.	dev.	time	Avg.	dev.	time	fitness	N_V
Pharmacies50A	10	**29348.2**	298.2	8.5	30524.6	688.2	12.1	30304.4	458.7	12.2	30999.3	1066.4	12.4	28900.93	8
	20	**26280.5**	400.4	8.4	27005.9	549.6	13.5	27322.0	731.7	13.3	27673.8	751.0	13.4	25507.86	4
	30	**25204.9**	327.9	9.8	26842.5	773.0	12.1	27160.3	839.5	11.8	26094.7	524.7	12.2	24689.29	3
Pharmacies50B	10	**44085.7**	544.6	7.1	44971.0	716.5	10.9	44796.4	681.1	10.8	45783.4	959.2	10.9	43076.89	8
	20	**40870.0**	471.1	6.7	41738.4	586.5	10.4	41895.7	548.9	10.7	42002.3	807.5	11.1	39926.54	4
	30	**39908.6**	438.0	9.5	41435.7	831.0	10.8	41492.4	576.0	10.8	41325.6	742.4	11.0	38967.98	3
Pharmacies75A	10	**57507.0**	618.7	16.8	61233.8	1799.7	21.3	61175.4	1703.7	21.5	61787.1	1529.5	21.3	56476.27	13
	20	**51921.7**	529.6	19.3	54641.6	1383.1	27.5	55293.2	1367.6	27.8	58069.9	2273.2	28.0	51183.94	7
	30	**50667.4**	688.3	19.1	53214.3	1239.5	23.7	54693.7	1961.9	23.4	54574.5	1251.0	23.3	49377.49	5
Pharmacies75B	10	**55162.0**	690.5	14.8	58348.4	1767.5	21.7	58293.4	2158.5	21.5	61080.7	1995.8	21.9	54207.02	10
	20	**51368.3**	770.7	15.2	53973.0	1156.7	21.0	55341.5	2120.8	21.2	56145.4	2307.9	21.4	50058.70	6
	30	**49488.2**	803.9	16.5	52286.9	1153.1	20.6	52508.1	1524.0	20.4	54595.1	1328.0	20.7	48390.30	4
Pharmacies75C	10	**50754.6**	492.5	16.1	53657.5	1520.1	21.4	53541.4	1211.3	21.5	53256.3	1590.0	21.7	49968.68	13
	20	**45065.9**	627.2	20.7	48353.1	1244.9	20.2	47844.2	1354.2	20.0	49932.1	1744.6	19.9	43955.45	7
	30	**43423.9**	665.2	15.3	46627.2	1225.2	22.3	47531.1	1518.4	22.4	48221.3	1535.5	22.8	42215.40	5
Pharmacies75D	10	**48300.3**	628.7	14.0	52374.1	1425.1	20.8	52217.5	1748.2	21.1	54503.3	1578.5	20.7	47114.97	11
	20	**44480.4**	1116.8	16.4	47981.8	2039.3	22.1	47399.2	1781.9	21.7	49857.4	1551.9	21.9	42954.08	6
	30	**42625.5**	550.6	18.5	45106.6	1118.3	23.0	45482.8	1896.0	22.8	47566.0	1442.0	23.2	41774.38	4
Pharmacies100	10	**69467.6**	818.8	30.1	75020.7	1751.8	42.3	75316.5	2396.7	42.7	76354.0	3955.8	43.1	67677.87	16
	20	**62263.3**	667.0	34.0	67934.8	4692.8	42.1	66227.3	2450.4	41.9	68005.1	3431.6	41.8	61269.73	8
	30	**60589.3**	1351.7	37.5	65996.5	2109.4	42.8	66767.5	2840.7	43.0	67591.4	3755.7	43.3	59156.44	5

TABLE II
AVERAGE RANKINGS BY THE FRIEDMAN'S NON-PARAMETRIC TEST

Method	AMCEA	GA_{SR}	GA_{RR}	GA_{LR}
Ranking	1	2.5714	2.7619	3.6667

TABLE III
UNADJUSTED AND AJUSTED P-VALUES OBTAINED BY HOLMS'S POST-HOC PROCEDURE USING AMCEA AS CONTROL ALGORITHM

Method	GA_{SR}	GA_{RR}	GA_{LR}
Unadjusted p	0.00008	0.00001	0
Adjusted p	0.00008	0.00001	0

In order to assess whether the difference in performance among the compared methods, are statistically significant or not, the guidelines given by Derrac *et al.* in [37] were followed. Before that, the Kolmogorov–Smirnov test over the 30 obtained values obtained for each instance rejected the null hypothesis that the results obtained come from a standard normal distribution. Friedman's nonparametric test for multiple comparisons is used to check if there are significant differences among the four methods. Friedman statistic (distributed according to χ^2 with 3 degrees of freedom) calculated is 46.428571. P-value computed by Friedman Test is 0. Table II displays the average mean ranking returned by this nonparametric test for each of the compared algorithms (The lower the rank the better the performance). According to this test, there are significant differences among results reported by the four compared algorithms, being AMCEA the one with the lowest rank.

To evaluate the statistical significance of the better performance of AMCEA, it was employed the Holm's post-hoc test using AMCEA as control algorithm. Table III shows the unadjusted and adjusted p-values obtained through the application of Holm's post-hoc procedure. Looking at this data, it can be said that AMCEA is significantly better than the rest of methods at a confidence level greater than 0.99.

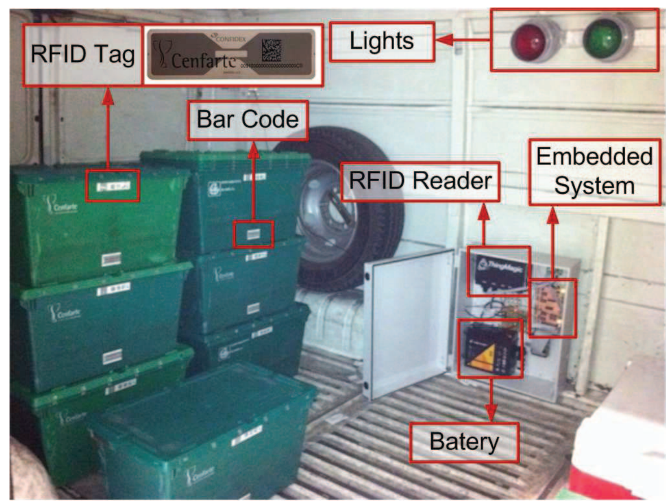

Fig. 9. Onboard system installed on the van. The containers (green boxes) and RFID tags can be seen at the left.

VI. VALIDATION OF THE AMI SYSTEM

The solution was tested in a pharmaceutical warehouse owned by the company Cenfarte S.A. Fig. 9 shows the system mounted inside the test van, where the different elements are remarked. As can be seen, containers are uniquely identified by the RFID tags or by a bar code. On the other hand, a battery supplies the RFID reader, the embedded system and the lights used to warn the driver about any incidence.

The vehicle follows routes up to three times a day. A route covers a distance of about 26.4 km and includes a maximum of 12 pharmacies. The tests were carried out during six days on which the route was run 14 times. The average route duration was 97 minutes. To minimize the impact of the tests on the warehouse, the evaluation was carried out in three phases, which are described next.

In the first stage, tests over the positioning system were developed during the first two days of validation with five iterations of the routes. Table IV reflects part of the results obtained in this

TABLE IV
RESULTS OF THE POSITIONING SYSTEM VALIDATION

		WH	Ph_1	Ph_2	**Unknown**	Ph_3	Ph_4	Ph_5	Ph_6	Ph_7	Ph_8	Ph_9	Ph_{10}	WH	Avg.
$Route_1$	In Route?	Yes	Yes	Yes		Yes	Yes			Yes	Yes	Yes		Yes	
	Stopped?	Yes	Yes	Yes	**-Yes-**	Yes	Yes			Yes	Yes	Yes		Yes	
	Stop time (s)	455	324	250	**-543-**	262	278			330	253	262		503	342
	Distance to Pharmacy (m)	0	18	15	**-402-**	19	17			21	32	16		0	54
$Route_2$	In Route?	Yes	Yes			Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	
	Stopped?	Yes	Yes			Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	
	Stop time	479	300			241	298	373	375		312	222	335	477	336
	Relative distance	0	16			13	19	25	31		12	20	28	0	16
$Route_3$	In Route?	Yes	Yes	Yes		Yes			Yes	Yes		Yes	Yes	Yes	
	Stopped?	Yes	Yes	Yes	**-Yes-**	Yes			Yes	Yes		Yes	Yes	Yes	
	Stop time	436	345	302	**-599-**	261			274	288		235	315	511	348
	Relative distance	0	24	29	**-301-**	20			13	15		12	17	0	43

TABLE V
RESULTS OF THE IDENTIFICATION SYSTEM VALIDATION

		WH	Ph_1	Ph_2	Ph_3	Ph_4	Ph_5	Ph_6	Ph_7	Ph_8	Ph_9	Ph_{10}	WH	Avg.
$Route_1$	Door-open time	395	265	220	202	238			251	231	192		288	266
	Identified containers	**-16/17-**	4/4	3/3	**-2/3-**	4/4			6/6	5/5	4/4		15/15	**-59/61-**
	Cargo alteration	**-1-**	0	0	**-1-**	0			0	0	0		0	**-2-**
$Route_2$	Door-open time	395	265	220	202	238	320	266		231	192	266	408	266
	Identified containers	20/20	6/6	7/7	3/3	3/3	4/4	3/3		4/4	5/5	3/3	17/17	75/75
	Cargo alteration	0	0	0	0	0	0	0		0	0	0	0	0
$Route_3$	Door-open time	395	265	220	202	238	320	266	251		192	266	408	266
	Identified containers	23/23	5/5	5/5	3/3	3/3	3/3	5/5	10/10		3/3	4/4	20/20	84/84
	Cargo alteration	0	0	0	0	0	0	0	0		0	0	0	0

TABLE VI
RESULTS OF THE COMPREHENSIVE VALIDATION OF THE SYSTEM

		WH	Ph_1	Ph_2	Ph_3	Ph_4	Ph_5	Ph_6	Ph_7	Ph_8	Ph_9	Ph_{10}	WH	Avg.
$Route_1$	Pharmacy assignment	OK	OK		OK	OK			OK	OK	OK		OK	OK
	Cargo identification	OK	OK		OK	OK			OK	OK	OK		OK	OK
	Incidences registered	0	0		0	0			0	0	0		0	0/0
$Route_2$	Pharmacy assignment	OK	OK	OK			OK	OK		OK	OK	OK	OK	OK
	Cargo identification	OK	OK	OK			OK	OK		OK	OK	OK	OK	OK
	Incidences registered	0	0	0			0	0		0	0	0	0	0/0
$Route_3$	Pharmacy assignment	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	Cargo identification	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	Incidences registered	**-1/1-**	0	0	0	**-1/1-**	**-2/2-**	0	**-2/2-**	0	0	0	0	**-6/6-**
Summary	Incidence reported to CO	**-Yes-**				**-Yes-**	**-Yes-**		**-Yes-**					
	Delay time in Inc. Report.	**-197-**				**-31-**	**-44-**		**-42-**					**-63-**

phase. In the table can be seen, for each route, the time spent by the driver to unload containers, as well as the distance from the parking space used by the van to the location of the pharmacy. During routes 1 and 3, the driver was told to stop for about ten minutes in a nonplanned location in order to validate the reconnaissance of the nearest pharmacy, resulting in incidents being logged into the XML file. As a result of this test, given the geographical issues, (some pharmacies are located in pedestrian areas), the need for modifying the structure of the database was highlighted. A field indicating the maximum distance of each pharmacy from the closest parking space was included.

In a second stage, tests were focused on the system for identifying the containers loaded in the van. This test was conducted six times. Table V shows one of the experiments carried out. During the development of this test, 59 containers were transported to pharmacies in the route. Similarly, 52 empty containers were transported back to the warehouse. One container's destination, the third pharmacy, was mislabeled at the warehouse. It is important to note that the system detected the change and immediately informed the driver by switching on the red traffic light. Additionally, the corresponding incident was reported upon exiting the warehouse.

Finally, in the third phase, the complete system was tested in three routes (Table VI). The driver was asked to be careful in the first two routes, in order to analyze incidence-free deliveries. In the 17 stops, the system confirmed the work carried out by the driver, switching on the green light. During the execution of the third route, the XML file containing the route information was manually altered by including three differences from the order given to the courier. Modifications included a container that was not loaded in the van (for the fourth pharmacy) and the switching of two containers to deliver to the fifth and the seventh pharmacies. The three incidents were reported by SMS and e-mail to the manager.

VII. CONCLUSION AND FUTURE RESEARCH

Nowadays, the quality of delivery systems has been improved gradually. Most of the existing solutions are aimed at the traceability of the products either in a manual or automatic way, but do not propose autonomously the tasks to be performed along the way from the receipt of the order. This could lead to a lack of accuracy in the information and in the generated incidents.

An adaptive multi-crossover evolutionary algorithm in charge of scheduling routes has been designed to generate delivery routes. The proposal incorporates adaptation in the probability of crossover and dynamic selection of the crossover operator to use over the population. In addition, a method to recalculate routes in case of an incident is provided. The routing problem model to be optimized by the proposal consider both travel times in normal and rush hours, with the aim of avoiding routes that could be congested at certain times of the day.

The solution proposed in the present paper is complemented with innovations such as the ability to perform cargo tracking and the monitoring of the distribution tasks interfere in the carrier's tasks. To achieve it, a solution including automatic cargo checking, adaptation of routes, and information to the central warehouse, without any intervention by the driver is implemented.

The routing algorithm has been compared with three versions of the classical genetic algorithm in a total of 21 instances of the scenario proposed, combining seven sets of clients from 25 to 100 and three capacities of the vehicles. The results show significant improved performances of the proposal in terms of quality of the solutions and execution times.

The AmI solution presented has been successfully deployed in a drug distributor of the city of Bilbao. In order to validate the adequacy and performance of the system, its functionality was monitored and analyzed during its integration, demonstrating the adequacy of the system for a real distributor.

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Enrique Onieva was born in Priego de Cordoba, Spain, in 1983. He received the B.E., M.E., and Ph.D. degrees in computer science with specialization in soft computing and intelligent systems from the University of Granada, Granada, Spain, in 2006, 2008, and 2011, respectively.

From 2007 to 2012, he was with the AUTOPIA Program at the Centre for Automation and Robotics, Madrid, Spain. In 2012, he was with the Models of Decision and Optimization Group, University of Granada. Since 2013, he has been with the Mobility Unit, Deusto Insitute of Technology (DeustoTech), Bilbao, Spain, where he carries out cutting-edge research in the application of soft computing techniques to the field of intelligent transportation systems. He has participated in more than 20 research projects and authored more than 80 scientific articles. His research interest is based on the application of soft computing techniques to intelligent transportation systems, including fuzzy-logic-based decision and control and evolutionary optimization.

Eneko Osaba received the B.Sc. degree in computer science and the M.S. degree in development and integration of software solutions from the University of Deusto, Bilbao, Spain, in 2010 and 2011, respectively. He is currently working towards the Ph.D. degree at the Deustotech Research Center, University of Deusto. His doctoral thesis is focused on artificial intelligence, specifically in the field of combinatorial optimization, studying and developing heuristics and metaheuristics solving routing problems.

Since 2014, he has been a Lecturer, teaching statistics at the University of Deusto. During the develop of his thesis, he was with Middlesex University, London, U.K., for three months. Since 2010, he has participated in several research projects, and has also contributed to scientific production, publishing several papers in international conferences and journals. In addition, he has been a program committee member of some conferences as GECCO or HAIS. He is a Reviewer in conferences and journals such as *Soft Computing*, *Evolving Systems*, and *Computers in Industry*.

Ignacio Angulo graduated with a Degree in computer engineering from the University of Deusto, Bilbao, Spain, in 1997. He is currently working towards the Ph.D. degree at the Remote Laboratories Line of Research, University of Deusto.

In 1998, he became a founding partner of the company IngenierÃ-a de Microsistemas Programados SL dedicated to the design and manufacture of development systems based on microprocessors. Since 2002, has been with the University of Deusto, where he teaches courses integrated in the Department of Industrial Technologies. He has participated in research projects in the area of intelligent transportation systems and in the area of remote control and tele-maintenance. He has also collaborated in writing six books focusing on the theme of the design of microcontroller-based systems published by McGraw Hill and Thomson Learning Publishing. In 2008, he joined the Deusto Institute of Technology - Deustotech within the Mobility Line of Research.

Asier Moreno received the B.Sc. degree in computer engineering and the M.Sc. degree in development and integration of software solutions from the University of Deusto, Bilbao, Spain, in 2009 and 2011, respectively.

Since 2010, he has been working as a Research Associate with the DeustoTech Mobility Research Team at Deusto Institute of Technology engaged in research and development projects. He has experience in a variety of technologies including JEE, .Net, and mobile development. His job with the Mobility Research Group has focused on wireless communications, embedded systems, and the development of software and services for vehicle communication and goods traceability.

Alfonso Bahillo received the Telecommunications Engineering degree and Ph.D. degree from the University of Valladolid, Valladolid, Spain, in 2006 and 2010, respectively. He received the PMP Certification at the PMI, Philadelphia, PA, USA, in 2014.

From 2006 to 2010, he was with CEDETEL working as a Research Engineer. From 2006 to 2011, he was working as an Assistant Professor at the University of Valladolid with responsibility for two subjects each year related to communications electronics and radiocommunications. From 2010 to 2012, he was with LUCE Innovative Technologies as product owner with responsibility in the field of indoor local positioning systems and ambient assisted living. Currently, he is working as a Postdoctoral Researcher at the University of Deusto. He has worked in more than 20 research projects and contracts. He is coauthor of 18 research manuscripts published in international journals of high impact, 7 research chapters of scientific international books, more than 30 communications in international conferences, and 3 national patents.

Asier Perallos received the B.Sc., M.Sc., and the Ph.D. degrees in computer engineering from the University of Deusto, Bilbao, Spain.

Since 1999, he has been working as a Lecturer in the Faculty of Engineering, University of Deusto. Currently, he is an Associate Professor, also accredited by the National Agency for Quality Assessment and Accreditation (ANECA) of Spain. His teaching focuses on software design and distributed systems, having taught several B.Sc., M.Sc., and Ph.D. courses. He is currently the Head of the Computer Engineering Department and in the past has been the Director of several M.Sc. in software engineering. He is also Head Researcher at the DeustoTech Mobility Unit, Deusto Institute of Technology (DeustoTech), where he coordinates the research activities of around 25 researchers. This research unit promotes the application of ICT to address smarter transport and mobility. In particular, his research background is focused on telematic systems, vehicular communication middleware, and intelligent transportation systems. He has over a decade of experience in R&D management, with tens of projects and technology transfer actions led, more than 25 JCR indexed publications and more than 50 other contributions in the area of intelligent transport systems and 2 Ph.D. dissertations supervised.