A RIA based VRP Information System: Application to Real-World Petroleum Products Distribution

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Abstract

Over the years, a large body of research and development covers the Vehicle Routing Problem (VRP) and its multiple characteristics, but few investigations examine it as an Information System, and far fewer as how it should be addressed from a development and implementation point of view. This paper tries to address this situation by describing the implementation decisions made by the authors toward the development of an Information System for a VRP solution. In order to achieve a viable VRP Information System in real world activities, authors have developed a Web-based solution with multiple web frameworks for each architecture layer, focusing on functionality and usability. To achieve these goals, authors have used SmartGWT as a powerful Web based RIA SPA framework with Java integration, and multiple server frameworks and OSS based solutions, applied to development of a very complex VRP system for a logistics operator of petroleum products.
Keywords: Web Framework, Web Architecture, VRP, Information System, Routes, Maps.

1. Introduction

Web technology evolution has been a constant from the beginning of the field: changing from CGI (Common Gateway Interface) applications to SOA (Service Oriented Architecture), from simple HTML to RIA (Rich Internet Application) [11] SPA (Single Page Application) [22] and from full page responses to REST services. This evolution has been going along with a strong and growing OSS (Open Source Software) community, which has driven great projects, from infrastructure project as Apache, Tomcat, Jersey, Spring, etc., to high level projects as OSM (Open Street Maps, [27]), that competes with the biggest corporations and offers a great service.

From development point of view, the creation of frameworks like GWT (Google Web Toolkit), SmartGWT [31], GXT, ExtJS, MooTools, EmberJS, AngujarJS, etc., are a huge advance in user interface programming tools and capabilities. These frameworks drive the innovation at UI level from simple HTML pages to responsive and dynamic RIA SPA (like the ones used at Twitter, Google plus, Gmail). This kind of RIA SPA leads the user to behave as with native applications, blurring the lines between web and local applications on perception level [28]. From these frameworks, SmartGWT and ExtJS are the best suited for RIA SPA enterprise class web applications, as they have extremely powerful widgets that drives user interaction in a native application way. SmartGWT is especially useful as it can be integrated into a Java web project, and compiled as a whole, making easy to develop and debug its applications. Other projects like Apache Struts 2, Jersey or Spring in Java language, or Epiphany and Symfony2 in PHP, are examples of enterprise accepted frameworks developed under OSS environment. These frameworks are designed to make easy web development of big scale architecture solutions, using technologies as JSON for data interchange or paradigms like REST for service layer design. The use of JSON is getting higher these days because of its simplicity and low memory footprint, which makes it ideal to be used on mobile devices with constrained resources.

At storage level there have been huge pushes on lasts years, mainly because of new NoSQL databases, and referred to web development it makes sense to look at document oriented storage solutions like MongoDB [23] or CouchDB [8]. Trying to replicate the way those works, there are traditional relational database solutions like PostgreSQL [30] adopting JSON as a native data type in their schemas, even allowing querying JSON data from SQL queries. As persistence solution, document oriented NoSQL databases has been integrated into solutions like Spring Data, and using Spring Data with Hibernate, while others solutions like MyBatis [24] provides a lower level of abstraction and do not try to integrate NoSQL Solutions.

Moreover, OSS project at higher level, as OSM, with a huge growing community providing data and support, has been able to build services with great added value, driving innovation with newer and focused projects like Leaflet JS [20], Nominatim [25] or OSRM [21]. These projects are based on Open Street Maps file format definition [29].

Currently, the use of these technologies enables us to implement highly complex applications with low development time, such as advanced route optimization, delivery scheduling and logistics planning software. During the last decade, there has been acknowledged a tremendous change in enterprise-oriented business software where traditional products have gradually left their place to integrated, friendly, usable and efficient solutions that would rigorously deal with every single business aspect of each individual enterprise. The VRP system presented in this article belongs to this category, as it is developed on SmartGWT, MyBatis and Spring Web-Development platform and possesses modular and flexible structure. Web-based techniques are less expensive, more efficient and lately have been the target of most development efforts. On the other hand, web-based solutions are able to easily interoperate with the whole supply chain entity.

VRP systems allow improving the process of designing the routes to follow by a heterogeneous fleet of trucks that transport a diverse number of products with different features (volume, cost, etc.), petrol and oil in this case, from n-depots to m-possible destinations (customers). There are several variants of the VRP [1, 2], [4], [5], [7], [12], [15, 16], [19]. In order to solve the problem, an extensive group of techniques have been addressed, and they can be classified into three categories: exact, heuristic and metaheuristic methods. All these techniques increase computer-time in order to obtain required optimization results and it is necessary to develop sophisticated programs in order to reduce the computation time. Here, a web-based system is constructed by using several metaheuristics algorithms. The system allows planning engineers to generate a near optimal vehicle assignment and routing plan based on daily shipping demands. The improvements compared to the current situation, embrace the maximum occupancy of trucks, total travelled distance, reduction of delivery times, minimization of distance travelled with minimal or no occupation of the truck, etc. The development of this system has been possible thanks to the use of SmartGWT, Spring, MyBatis, OSRM, Leaflet and OpenStreetMap technologies.

Over the years, a large body of research and development covers the VRP problem and its multiple characteristics, but few investigations examine it as an Information System, and far fewer as how it should be addressed from a development and implementation point of view.

This paper tries to address this situation by describing the implementation decisions made by the authors toward the development of an Information System for a VRP solution. At the conceptualization phase of the system, authors have been aware of some needs that must be fulfilled to get the system on duty: every order must be served, not matter how hard, long or difficult it is; security on handling and transportation is key; traceability of operations is a must; environmental concern is inside all business process; multiple areas of distribution, with little to none common frontier; constant changes of customer orders.

These needs lead to the creation of key areas like multiple planning locations usually based on truck depots, simple routing from point A to B, manual operation, integrated information of all resources and non-blocking operation, is given, all of them described in Section 2. In Section 3, the VRP algorithm characteristics are described. Section 4 describes the use case where the VRP Information System is applied. Section 5 summarizes the findings and characteristics of the developed VRP Information System.

2. VRP Information System

2.1. Multiple planning locations

Given the area of a country like Spain, it's not logical to set a unique operation centre for fuel distribution. There are some factories/refineries settled along the country in key places where fuel products are ready to serve to the final distributor (gas stations, large buildings, etc.)

Replicating this logic, the fuel distributor uses to set a base for their trucks near the factories/refineries, so it is faster and cheaper to make fuel distribution in this way. With this configuration in mind, the business is ruled by resources localities, and the planning of an area is held by plan engineers sited in that area. This gives better understanding of area based constraints and risks, and makes easier to plan accordingly to the most up to date fleet and customer information. On the other way, the Information System must take this locality feature into account and be able to operate in multiple locations, while sharing all data about fleet and customers so managing staff can get over any problem that could arise in day by day operation. These constraints lead to development of a Web-Based Information System, so it can serve to multiple clients on multiple locations. By contrast, the approach used to the date on Spanish fuel distributors is the use of single seat software, with local databases, unshared or hard to share information, and local optimisation software.

2.2. Simple Routing

The objective of simple routing is to provide a route from point A to point B with 3 information components: distance, time and intermediate GPS coordinates at a fixed zoom level. While it seems a simple problem, there are some initial constraints which must be addressed because simple routing is used for two different objectives: GUI guidance to planning engineers in order to visualize the real route their trucks will cover on a map; and create a distance/time matrix, so it can be used on VRP optimization. Simple routing calculation is handled by OSRM component. This component is built by a dedicated web server on a dedicated machine of the Information System. It loads all map data into RAM memory, so it won't use the disk when OSRM is on duty. It can handle multiples route queries, but it's limited on the amount of CPU cores and how the requests are made.

We have measured 900 request per second with an Intel Core i7 3770 CPU, and while it's a good result, it's not good enough to keep the pace with a VRP problem, NP-hard by nature. The distance matrix creation problem gets harder as new destinations are added to the problem, so a VRP problem with 1 depot and 39 destinations gets n^2-n viable routes: 1.560. But if the number of destinations grows to 199, the number of viable routes goes up to 39.800 routes. We have found that the range of the number of destinations varies from 200 to 500 in real world problem, and it must fulfil orders for about 5 million litres per planning job and zone. These lead us to a worst case scenario of 249.500 viable routes, and that could suppose more than 4 minutes only to get ready to launch VRP algorithm process.

To address this situation a route cache was built. All route queries made by *Chronos System* goes through a database backed cache system to reduce the number of queries made to OSRM component. This approximation gets three key benefits: firstly, the distance matrix creation process is much faster as only new destinations must be processed. Secondly, the routes could be tweaked offline to adapt them to business needs (tolls, dangerous routes, legal limitations, etc.). Thirdly, OSRM component gets more available time to be used by other users on their planning jobs. At the time of writing this paper, the cache system is running with more than 17 million routes, which are refreshed periodically to reflect map's changes and optimizations.

2.3. Manual Operation

As long as *Chronos System* is designed to fulfil the needs of fuel distribution logistic, it must check some compatibility issues when serving the orders to the clients. These issues go from checking capacity of the truck, to marketing compatibility or even contamination episodes with environmental consequences. Nevertheless, all those checking must be pledge to plan engineers will, because there are cases that get out of control easily and must be addressed. These cases go from a human error while handling the fuel, to an emergency call for fuel to firefighter's helicopters or planes, or to terrorist attack to factories and/or depot facilities. Given that these situations are completely out of usual behaviour, cannot be forecasted, and the way to resolve them depends on the situation itself, the *Chronos System* must be able to ignore all its systems checks and usual capabilities so plan engineers can do their distribution plans as they need with the maximum help and minimum limitations from the *System*.

2.4. Integrated Information

While almost all Information Systems tends to integrate all business information, this goal is key in a VRP environment. Within a VRP problem there are multiple constraints which must be testes, checked and evaluated to be able to know if a result is a valid/viable result or if it should be discarded. The present case is extremely difficult in these areas, as it requires multi-element cross compatibility checking, as it may need to check if the products can be downloaded by a pump pulse, or how many litres are wasted on the discharge hose if has a longitude or another and if that quantity will lead to chemical incompatibility with the next download. At the same time, all business distribution resources must be compatible checked with customers (e.g. it's impossible to serve an order with a 3 axis truck in a historical city center, it's too big. There're other constraints with hose length, or with some military facilities). The system must observe and preserve the legal constraints on drivers rest, and it have to find who is the best driver for each order, given his work calendar and other constraints (holidays, inactivity for medical reasons …)

As shown before, all information is needed to be available to VRP so it can pick a good solution to optimization problem, but taking care of all information implies that the storage of the Information System must fulfil some needs: it must be ACID compliant. Multiple changes must be taken into account as one atomic change, even if they affect multiples objects/entities: it influences the choices available, as Document Oriented NoSQL Databases do not support ACID at database level at this time (only at document level, which it is not enough). The system should be able to be used easily in web based solutions: from persistence view, it should integrate with a persistence solution, and from data logic view inside web service layer, there will be data which should not be processed, but passed, so there is a clear advantage to store it in its original format.

2.5. Non-blocking Operation

While Web UI has gone a long way to lead to non-blocking interaction, using Ajax to be able to send and receive multiples request to a web server, and it is now on common use, non-blocking operation *inside* the service layer of a web server is not so common, and leads to unusual situations. At a VRP Information System there are some processes that require some time to complete. Given the need of information to create the data needed to a VRP optimization, it is easy to understand that it may take time to complete. In order to address these situations, the *Chronos System* works with asynchronous actions and a pool of semaphores to route the internal logic at service level. By taking this approach, when the *Chronos System* receives a request on one of their asynchronous actions, it split to logical routes inside server code, one to respond with the state of the async job requested, and other to complete the async job if it was not already at work. Hence, the system has a pool of async jobs executing that can be managed by users. Those jobs go from creating a distance/time matrix to control VRP algorithm as an external process, or to update at night the whole route cache system if it is needed.

3. Vehicle Routing Problem (VRP)

The distribution problem in general started with two classical problems in combinatorial optimization: the Traveling Salesman Problem (TSP) and the Vehicle Routing Problem (VRP). The TSP consists, from a departure point, to visit a set of customers with one single truck and to come back planning its tour by finding the sequence of customers with the lowest possible total cost. Historically, [10] is the first work that introduces TSP problem by proposing resolution's methods. The vehicle routing problem addresses the case where each customer has a given request. It consists in determining several tours that all start and end at the depot and where each customer is visited once by a single truck. The first work that addresses the VRP is [9]. The VRP generalizes the traveling salesman problem (TSP) and is much more difficult to solve than the TSP [17]. As we have seen, the physical distribution problem in general, is not a recent problem. As a component of the supply chain, includes a set of activities executed to obtain the delivery of a product from the production location to the end customer. Problems related to physical distribution are: selection of distribution channels, determination of customer service level, distribution centers, location planning, inventory management, transportation means selection, fleet composition, delivery scheduling and vehicle routing, etc., and the objective is double: to minimize the total transportation cost while rationalizing the vehicles utilization. In this sense, vehicle routing refers to a broad group of problems that could be expressed as following: a finite set of customers at fixed locations with defined demand, must be supplied with goods by a number of vehicles having a finite capacity and predefined starting points and terminals.

The vehicle routing problem literature is abundant. At the origin of routing problems, [18] provided a bibliography of 500 studies. [13] presents a VRP literature classification, based on a review of about 1,500 documents. Extending the basic VRP approach, numerous variants have emerged over the years, among which, the most discussed are: CVRP ("Capacitated VRP"): *each vehicle has a limited capacity*. MDVRP ("Multi-Depot VRP"): *the seller uses several depots to supply customers*. PVRP ("Periodic VRP"): *orders can be taken only on certain days*. SDVRP ("Split Delivery VRP"): *customers can be served by different vehicles*. SVRP ("Stochastic VRP"): *some values such as the number of customers, their demands, length of service or travel time are random*. VRPB ("VRP with Backhauls"): *customers can return the goods*. VRPPD ("VRP with Pick-Up and Delivering"): *customers have the option to return some goods to depot*. VRPSF ("VRP with Satellite Facilities"): *vehicles can be supplied without returning to the central depot for other auxiliary route*. VRPTW ("VRP with Time Windows"): *each customer has to be served within a certain time window*.

We can state that the VRP and all extensions listed above are a generalization of the TSP ("Travel Salesman Problem") and, therefore, are within the combinatorial optimization problems, which means that, from the standpoint of computational complexity, is one of the most complex because it is NP-Complete kind of problem: It cannot be solved in polynomial time [3], [14]. In order to solve the VPR problem, a group of techniques have been addressed. They can be classified into three categories: exact, heuristic and metaheuristic methods. We can say that the exact methods are efficient in problems up to 50 depots [2] due to the computational time constraints. Furthermore, heuristic methods provide us with acceptable solutions obtained by a limited exploration of the search space. A review of these can be found in [26]. Finally, the metaheuristic techniques, developed in the late 90s, are characterized by performing a search procedure to find acceptable solutions by applying domain independent operators that modify intermediate solutions guided by the suitability of its objective function. Within these Neural Networks, Tabu Search, Genetic Algorithms or Ant Algorithms can be found, among others. A review of these methods can be seen in [6].

4. Case Studies

4.1. Background

The case study concerns one of the biggest Spanish companies for oil distribution products by road. The enterprise is located in different areas of Spanish territory and operates on great public and at the same time has several individual customers. Every day, several times a day, a customer network needs to be serviced by a fleet of heterogeneous capacitated vehicles located on a several depots or distribution centers. A Complex-VRP system was designed in order to automatically generate vehicle routes, which vehicles should deliver to which customers and in which order, minimizing simultaneously the vehicle cost and the total distance travelled by the vehicles, subject to the high number of constraints, such as: the vehicles are multi-depot or single-depot; the capacity of a vehicle cannot be exceeded; a single vehicle supplies each customers demand; the number of vehicles used is pre-determined; schedule of the drivers must be respected; the number of drivers is pre-determined; the time to serve the customers should be respected; the shipping demand of a depot cannot be divided. It should be delivered by the same vehicle, unless the shipping demand of the depot exceeds the loading capacity of a vehicle; the time-window constraint is known, the driver will be given the time limitation so that over-time driving can be eliminated; the cargo loading cannot exceed the vehicle loading capacity at each delivery; there are over ten different types of products; etc.

4.2. System Implementation

The Chronos System is composed of multiple modules working as a whole to achieve the distribution's plan. Taking into account all modules, the Chronos System (Figure 1) has a management module, an ERP module, an Orders module and an Optimization Module. These modules are integrated into the System as first class citizens, as its functionality is needed to make the system work as it should. There are other modules like HCAE or RTCM (Real time Control Module), that are not indispensable to the planning work, but are needed for subsequence business process. Other external modules are the Web Map System, generated with Leaflet framework and integrated into SmartGWT and Spring, and the OSRM module as high performance routing system installed on a different machine. All modules are connected to the central database, where all information is kept always in a coherent way, warrantying all data is up to date and ready to use in VRP optimization process. To develop all these modules, a combination of SmartGWT, Spring, MyBatis, LeafletJS, OSRM, OSM and PostgreSQL is used.

4.3. Implementation Benefits

Through the use of the developed VRP system, the enterprise obtained as results: significant cost-reductions; improvement of the maximum occupancy of trucks; reduction of the total travelled distance; reduction of delivery times; minimization of distance travelled with minimal or no occupation of the truck; improving business processes of major importance; reducing personnel's occupation times; more flexible and efficient planning; improved communication and data, transfer of critical information for the whole enterprise; instant access to real-time data; etc.

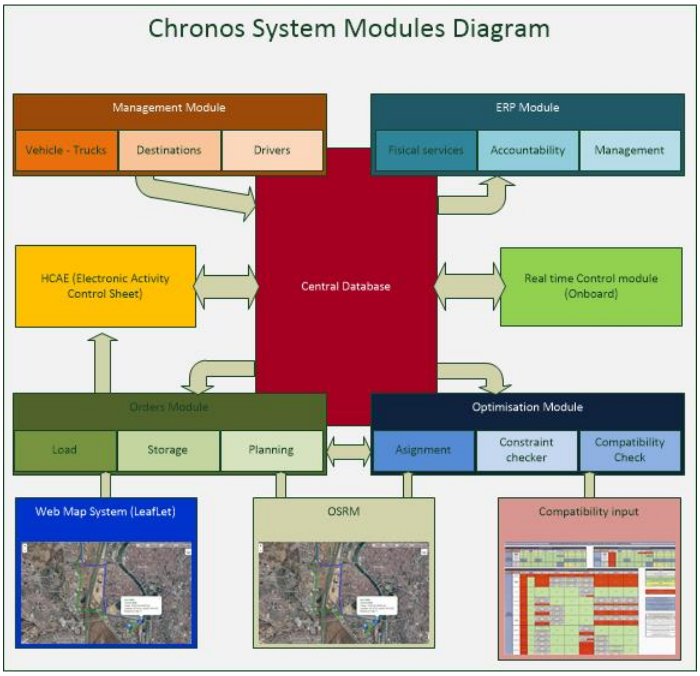

Fig. 1. *Chronos system*: Modules diagram.

5. Conclusions

In this paper we have used SmartGWT framework for RIA SPA UI, Spring for service level architecture at web server, MyBatis as persistence solution, PostgreSQL as database backend, OpenStreetMaps as map data source, OSRM as high performance routing engine and LeafletJS as map visualization framework, building a technological stack ideal for VRP systems. The use of these technologies has allowed the development of a web-based complex vehicle routing planning system that helps the company to solve the daily vehicle routing problems. The system routing problem developer for the case company was formulated based on the company's current delivery network, and it is able to reduce the operating costs and increase the competitiveness of the company. With the aid of this system, the time needed to generate a routing plan is significantly reduced if compared with the time needed in the older planning system, and helps to shorten the learning curve for new staff in dealing with the routing process. As a result, the overhead cost is reduced and the possible loss due to poor routing plans is avoided.

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