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A Vehicle Routing System Supporting Milk Collection

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Abstract

This paper describes a computer-aided custom designed support system to reduce milk transportation costs. The model was developed in co-operation with Uruguay National Cooperative of Milk Producers (Conaprole). The vehicle routing model contains three inter-communicating parts: a) a Geographic Information System (GIS), b) external and internal interfaces, and c) a Vehicle Routing solver that includes heuristics inspired on the strategy of "cluster first, route second". The distance and time matrices are calculated directly on the cartography. The first official digital map of Uruguayan roads was digitised according to the model requirements. As a result of the system implantation, large benefits are reported in haulage savings and in improved efficiency in milk collection management. The solution cost depends on the choice of clustering algorithm and on problem topology.

Key words

Combinatorial Optimisation, Decision Support Systems, Geographical Information Systems, Vehicle Routing Problems.

1. Introduction

The National Cooperative of Milk Producers (Conaprole) is the largest Uruguayan agro-industry and spends millions of dollars annually on milk transportation. The milk is collected by bulk tankers from thousands of farms by many transportation companies, and delivered to more than a dozen dairies. Route planning is under the responsibility of each transportation company hired. Conaprole managed milk using manual procedures but that method became inefficient as the number of farms and production levels increase. The development of a computer-aided system was proposed and implemented with the following objectives: a) to optimise costs and b) to support the process of controlling and planning the collection routes made by the haulage firms bulk tankers [19].

A route is a sequence of geographically located points (farms in this case), beginning and ending at another geographically located point (one of many dairies). Vehicle routing can be stated as the problem of optimising cost of delivery through a defined set of locations, taken certain constraints in consideration [1], [6], [9], [14]. The classic Vehicle Routing Problem (VRP) designs routes for vehicles housed at a single central depot, which services all customers, minimising total travelled distance and/or total fleet travel time. Customer demand is known in advance. Each vehicle has the same fixed capacity and the daily time schedule is constant. Vehicle routing and scheduling problems become quickly more complex for more than one central depot, heterogeneous vehicles capacity, various time restrictions in which a pick-up or delivery can be made (open and closed times), backhaul considerations, and multiple daily routes for a vehicle [10].

Vehicle routing holds a central place in logistics management [2] and been widely studied in the Operation Research literature [10], partly due to its practical importance but also to its intrinsic difficulty. VRP is a combinatorial problem in the class called NP-hard, and hence unlikely to be solved in acceptable computational time, which is polynomial in problem size [11]. Solution methods may be exact or approximate. Exact algorithms solve relatively small problems, for instance a VRP with time windows and 100 customers is reported in [4]. In the case of approximate methods, larger problems can be solved, and the literature reports a number of heuristics that have been satisfactorily tested [1], [10], [16], [17]. Meta-heuristics have also been proposed [3], [5], [10], [8].

The use of a Geographical Information System (GIS) is of significant importance in the context of VRP as elements of the problem can be located geographically. A route then becomes a sequence of geographical points and routes are constructed using geographical data. GIS is an organised collection of hardware and software to efficiently capture, store, manipulate, analyse and display all forms of geographically referenced information [13], [22]. The topological database of the GIS (nodes, arcs, polygons, etc) corresponds to digitised cartography, which would include in the case of this paper the location of farms and dairies, highways, roads, paths, bridges, rivers, cities, small towns and other geographical references that may orient drivers while carrying out assigned journeys. The descriptive database of the GIS contains dairy descriptive data such as demand, capacity, reception time, and milk required quality.

The objective of a vehicle routing system is to provide high level of customer service while keeping and keep operating and investment costs as low as possible. It is fairly rare for a company to fit the mould of the classic VRP because of route restrictions, fleet characteristics and application restrictions. Although routing and scheduling models have evolved technologically since 1997, software companies have not reflected such advances [7]. Therefore custom designed developments are still advised for applications with particular restrictions as in the case dealt with in this paper.

Vehicle routing applications resulted in haulage savings between 5% and 10%, a significant cost reduction in monetary terms. The savings observed when the system described in this paper was applied to Conaprole were significantly higher, estimated at 16% of haulage costs and these results may yet be improved further.

The milk problem contains multiple depots (14 dairies), multiple suppliers (2500 farms), and a heterogeneous fleet (70 bulk tankers of different capacities). Farms and dairies have different supply and demand capacities and multiple time windows, i.e. more than one feasible time interval where collection and delivery are allowed. Therefore the Conaprole milk problem can be classified as a Vehicle Routing Problem with Multiple Depots, Multiple Time Windows (MDVRPMTW) and heterogeneous fleet [19]. The details of the mathematical model and algorithms are presented in [12].

The rest of this article is organised as follows. The components of the computer-aided system are discussed in Section 2, and the vehicle routing tool in Section 3, while Section 4 presents conclusions and future lines of work.

2. The milk collection routing tool

The computer-aided system named "Inforut" contains three inter-communicating parts, which used individually or in combination support different milk collection processes :

1. A Geographical Information System (GIS), a topological and descriptive database of the problem,
2. A custom developed graphical user interface and internal interfaces,
3. A Vehicle Routing Solver, which is a collection of heuristic procedures.

The tool is implemented under the GIS Arc-Info 7.0 and runs on a Unix platform (SUN workstation). The descriptive database was developed in Oracle, designed as a sub-system of the Conaprole central database. Routing procedures were programmed in Common C. The graphical user interface was developed in the AML-language of Arc-Info [22]; efforts were put into developing a user-friendly tool, easy to learn and use. The interface of access, processing and visual representation of the descriptive data was developed in Genexus [23] accessing to Oracle, independently of Arc-Info.

The following basic functions for the routing tool are available :

- Management, updating and graphic visualisation of the following data points: cartography, farms, dairies and urban areas location, the transportation network with roads classified by type (highways, roads, paths, streets, etc.) as well as quality and speed restrictions, and finally descriptive data including identification, service time, capacity, demand, type of production, milk supply, milk tank capacity, milk quality;
- Elementary cartography calculations such as shortest and quickest route. Distance and time matrices are also calculated in advance;
- Fast graphic visual presentation of generated solutions and alternatives which may result from input data changes, thus supporting quick decision-making,
- Manual intervention allows routes to be redesigned to account for experience, accidents and other unforeseen factors.

Since an exact solution method was not considered an attainable goal, the strategy was to use a "cluster first, route second" heuristic [1]. The multiple depots problem is divided into several simple vehicle routing problems with multiple time windows (VRPMTW) and heterogeneous fleet.

The basic algorithm consists of three steps :

1. For each dairy, define a zone of influence, i.e. the set of farms to deliver daily production (assignment algorithm).
2. Estimate size and composition of the required fleet for each dairy.
3. Construct the set of routes taking into account steps 1 and 2 (routing procedures).

The first step uses an extension of the Generalised Assignment Algorithms as described in [12]. When assigning farms to dairies, time windows are taken into account. In the second step, fleet composition for each haulage firm, and the previous day journeys are considered. A known number of bulk tankers is assigned to each transportation firm, which is responsible for a geographic region with its dairies and farms. The third step uses an extension of one of Solomon's insertion heuristics [16]. The algorithm also allows heterogeneous fleet, multiple time windows, re-usability of bulk tankers and different route origin and destination, as described in [12].

Operational level procedures deal with two important functions : a) routes control and b) manual planning. The first function controls the routes mileage reported by the haulage firms for payment. A Travelling Salesman Problem (TSP) is solved, and shortest and quickest routes are displayed by using Arc-Info Networks-module.

Manual planning has proved useful in the case of floods case and other unexpected events. Managers simulate simple scenarios, based on past events, incorporating changes and observing the consequences. Independently, a routing is executed for each dairy. Farms assignment is obtained in advance either manually (graphically from the cartography) or by executing one of the implemented assignment algorithms.

3. Implementation of the Routing Tool

One of the most complex parts of the project was setting up the infrastructure with the necessary data to run the algorithms and the routing tool. Specific procedures had to be defined for the calculation of distances and times matrices, and the maintenance of the farms descriptive data. The strategy adopted was to do these procedures gradually. First, a representative zone of the total problem was digitised to create corresponding database and test the tool. Figure 1 shows the Uruguayan map where the southern milk-producing basin digitised in the first stage is coloured. Figure 2 shows the result of applying an assignment algorithm in this region. Figure 3 shows the results of running the control function, and the quickest route is displayed. After testing the representative zone, neighbouring areas were gradually incorporated until the whole country was covered in May 2000.

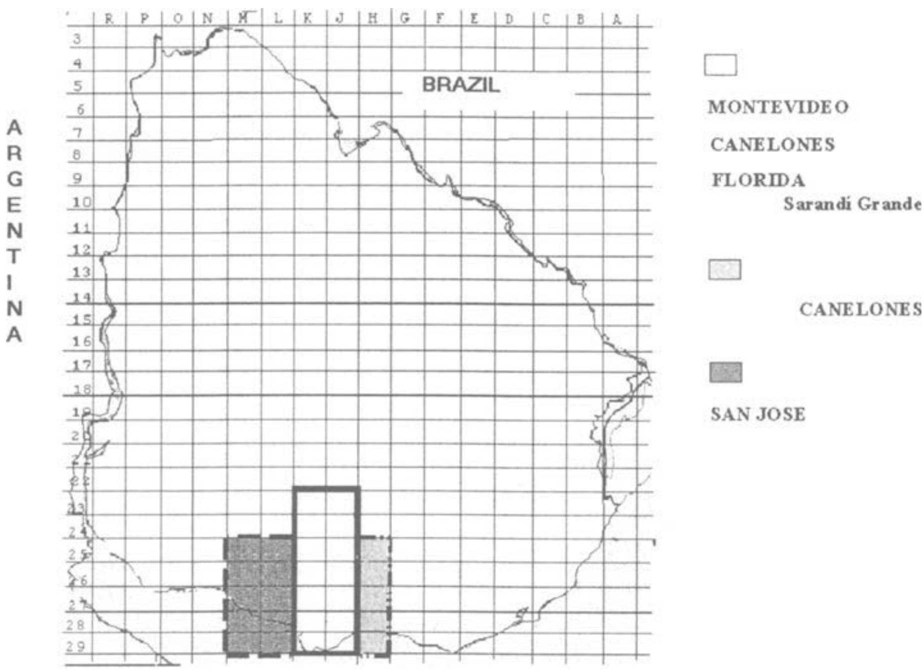

Fig. 1

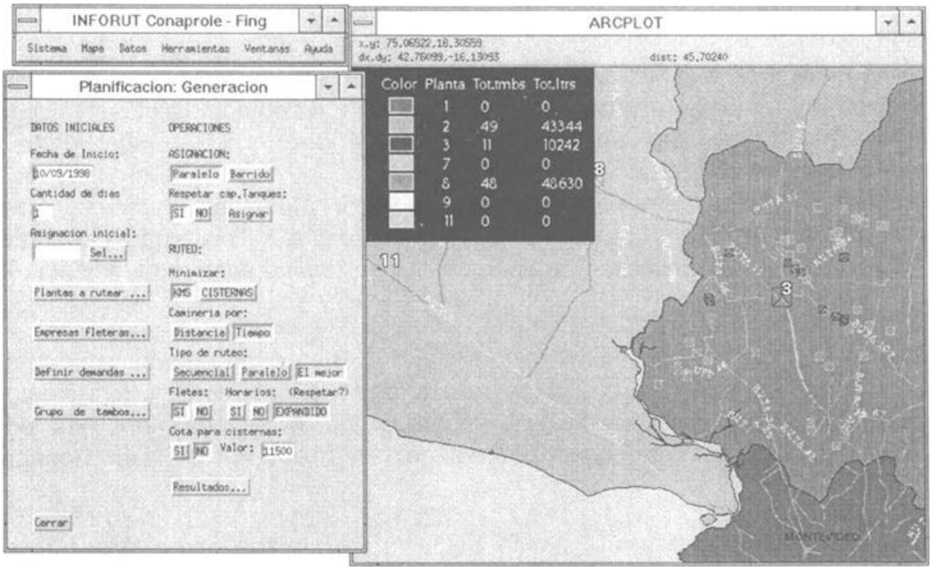
INFORUT Conaprole - Fing
Sistema Mapa Datos Herramientas Ventanas Ayuda
Planificacion: Generacion
DATOS INICIALES
OPERACIONES
Fecha de Inicio:
ASIGNACION:
Paralelo Barrido
Cantidad de dias
Respetar cap.Tanques:
SI NO Asignar
Asignacion inicial:
Sel...
RUTEO:
Minimizar:
Plantas a rutear ...
KMS CISTERNAS
Camineria por:
Empresas fleteras...
Distancia Tiempo
Tipo de ruteo:
Definir demandas ...
Secuencial Paralelo El mejor
Fletes: Horarios: (Respetar?)
Grupo de tambos...
SI NO SI NO EXPANDIDO
Cota para cisternas:
SI NO Valor: 11500
Resultados...
Cerrar
ARCPLOT
Color Planta Tot.tmbs Tot.ltrs
1 0 0
2 49 43344
3 11 10242
7 0 0
8 48 48630
9 0 0
11 0 0

Fig. - 2

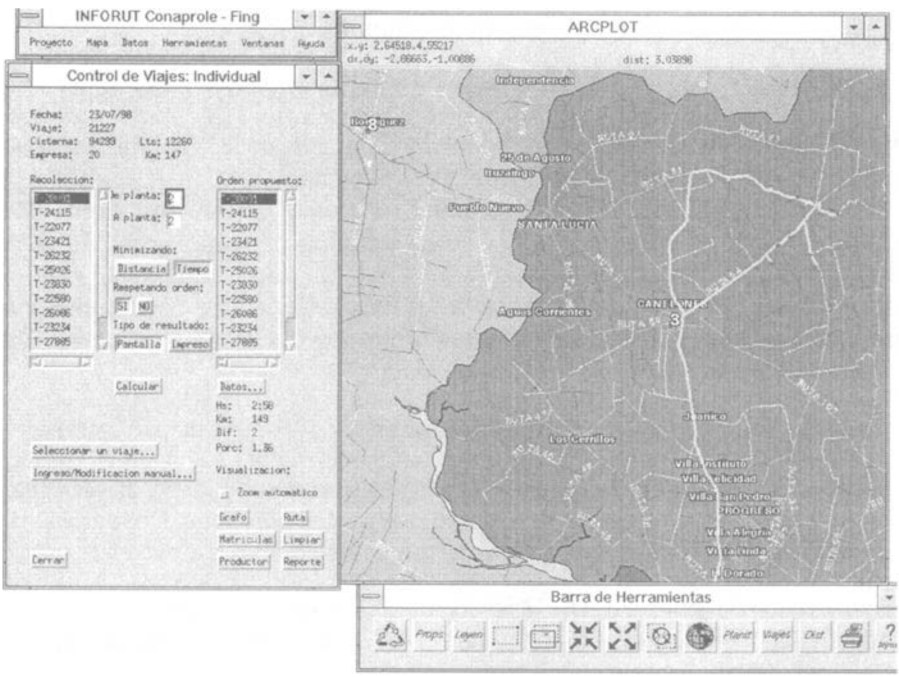
INFORUT Conaprole - Fing
Proyecto Mapa Datos Herramientas Ventanas Ayuda
Control de Viajes: Individual
Recoleccion:
Orden propuesto:
De planta:
A planta:
Minimizando:
Distancia Tiempo
Respetando orden:
SI NO
Tipo de resultado:
Pantalla Impreso
Calcular
Datos...
Seleccionar un viaje...
Ingreso/Modificacion manual...
Visualizacion:
Zoom automatico
Grafo Ruta
Matriculas Limpiar
Productor Reporte
Cerrar
ARCPLOT
Independencia
25 de Agosto
Pueblo Nuevo
SANTA LUCIA
Aguas Corrientes
Los Cerrillos
PROGRESO
Barra de Herramientas

Fig. - 3

4. Conclusions and future developments

When solving a real-life problem, the core theoretical model may be a minor part of the total solution process. The time and work complexity involved in obtaining, maintaining and updating topological and descriptive input data are usually underestimated. Special care is required during the digitalisation process as distance and time matrices used by the solution algorithms must rely on the GIS network, i.e. digitised cartography. The first digital official road cartography for Uruguay took into account the milk collection routing tool requirements [24].

The system development process influenced company management and improved efficiency. After an initial rejection and distrust period, haulage firms now ask Conaprole for shortest and quickest routes; and are incorporating improvements into their own organisation. Applying a subset of the system functions has led to substantial reductions in the costs of haulage, estimated at 16 % for Conaprole [20], [23].

In the near future "Inforut" should be inserted into the company's computer integrated system [21]. The assignment algorithms depend on the geographical topology of the problem instance to solve [18]. As total solution time and cost depends on the choice of algorithms, further research in this direction may lead to further improvement in management procedures.

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