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Abstract: In this paper, we propose a work domain analysis for the vehicle routing problem. This analysis facilitates the identification of the problem constraints. The analysis is done through an abstraction hierarchy which facilitates an ecological user-interface design. The proposed decision support system and the ecological interfaces are presented. Finally, we propose an experimental study in order to evaluate the influence on the user for one of these interfaces.

Keywords: Decision support systems, vehicle routing problem, ecological interface design.

1. INTRODUCTION

Nowadays there exists an aggressive competition between the companies involved in goods and services production. The delivery times have to be reduced as much as possible and often have to be adapted to customers requirements. The companies have increased their interest in the transportation optimization in order to keep being competitive.

Besides the economical and social features, the vehicle routing problem (VRP) is a very interesting combinatorial problem that has drawn, more particularly in the last two decades, the researchers attention. We find in the literature a large number of methods, specially heuristics and metaheuristics, to efficiently solve the existing variants of the problem (Barnhart and Laporte, 2007; Golden et al., 2008; Toth and Vigo, 2001).

We focus our study in the design of a decision support system (DSS) for the VRP. Many examples of DSSs are available in the literature. In Basnet et al. (1996) a DSS for the construction of milk tanker routes in New Zealand is proposed. Similarly, in Ruiz et al. (2004) the authors propose an interactive DSS for a feed compounder company. More recently, Ray (2007) and Santos et al. (2008) propose spatial decision support systems integrating Geographical Information Systems in the DSS. Finally, Mendoza et al. (2009) propose a DSS for the Bogota water and sewer company.

However, the cited DSSs are focused in the operations research methods to solve each particular problem. We consider that the DSSs have two important limitations. The first one is that human factors are not much considered in the solving phase of the problem. It is important to allow the human be part of the system. We consider that the robustness of the proposed solutions may increase if the human is allowed to act on constraints and if he participates in the construction of the solution. It is usually noted that experienced individuals build schedules that are robust enough to disturbances. For example, the user has enough knowledge and know-how to anticipate emergencies, vehicle breakdowns, traffic jams, driver substitutions, and so on (see Cegarra (2008) for a discussion on human contributions).

The second limitation is that these models are not ready to deal with the dynamics of the problem. In the logistics domain, the constraints are constantly changing. The model still has to remain valid recovering these changes. The DSSs that we find in the literature are not adapted to deal with the changes, for example the proposed solver tools are designed to solve a specific type of problem and do not allow to consider new types of constraints without a re-design of the system.

We present in Section 2 a work domain analysis which is the first step for the design of a DSS for the vehicle routing problem. The architecture and the user interfaces of this system are presented in Section 3. Finally, we present in Section 4 an experimental study proposed for the solution selection interface in order to evaluate its characteristics compared with other types of interfaces.

2. WORK DOMAIN ANALYSIS

The vehicle routing problem consists in determining the routes of a fleet of vehicles for the transportation of goods or passengers according to some customer demands (delivery, pick-up...). A large number of constraints have to be considered to determine these routes (delivery times windows requirements, capacity limitations,...).

We propose a work domain analysis (WDA) for the VRP. We believe that the model derived from this kind of analysis can be well suited to take into account the user and more generally the human factors perspective (see for instance Higgins (1999, 2001)). The underlying idea is that if the model contains all constraints having an influence on the way the solution is built, it also considers constraints relating to the Human. On the other hand, if the great majority of constraints are considered in the model, normally it will be adapted to deal with the unexpected and to resist the long-term changes of the situations.

We propose an early decomposition of the domain, analysis and identification of the structural limits of the problem. We use the abstraction hierarchy proposed in Rasmussen et al. (1994); Vicente (1999a) for this analysis. The abstraction hierarchy ensures an exhaustive decomposition of the work domain necessary to take into account the restrictions of the problem (Figure 1).

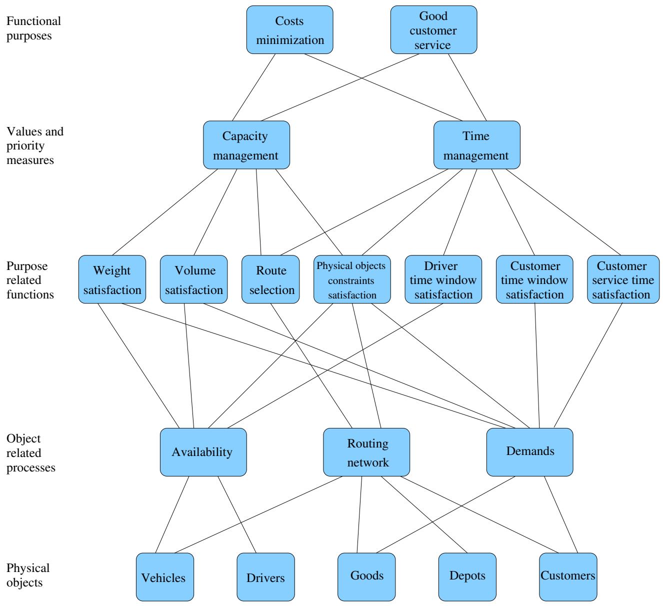


Fig. 1. Work domain analysis of the VRP using an abstraction hierarchy

The abstraction hierarchy levels represent the levels of user reasoning to solve the problem. We decide to keep the 5 levels proposed in Vicente (1999a) which are all necessary for the considered problem.

At first level, we define the primary objectives of the work system. In transportation, the two main objectives to satisfy are costs minimization and customer satisfaction. Sometimes the criteria may be contradictory, for example, a delivery delay might lead to a decrease of transportation costs, by reducing the time of route. The DSS has to offer several evaluation criteria in order to facilitate the selection of the best adapted solution (for example, increase customer satisfaction or decrease transportation costs).

At second level, we define the criteria to be used to decide whether the work system is achieving its purposes. In order to keep the genericity of the analysis, we decide to not describe criteria at this level but rather the concepts from which the criteria may be derived. These concepts are efficient capacity management and efficient time management.

The functions required to achieve the purposes are shown at third level. These functions point the constraints to take into account in order to achieve the objectives of the system. The capacity satisfaction (weight and volume), the route selection and the satisfaction of the constraints between the physical objects have an influence on the criteria derived from the capacity management. An efficient time management depends on the routes selected, the respect of the drivers working times, the customer service times, the delivery customer time requirements, and the constraints between the objects.

On the two remaining levels, we find the physical objects of the vehicle routing problem (vehicles, drivers, merchandises, depots, customers, and demands) and the processes defining the capacities and limits of physical objects. The object processes are the availability of drivers and vehicles, the routing network and the customer demands. The routing network is usually defined by the location of the depots and customers, but also in some cases by the kind of vehicles used or the type of goods transported.

The decomposition of the problem remains very generic according to studies and problem descriptions found in the literature. A validation for different real problems is necessary. Nevertheless, we consider that most of the vehicle routing problems are covered for the proposed work domain analysis and only some particular problems may required other components not represented on our analysis.

3. DECISION SUPPORT SYSTEM

In this section, we propose a DSS architecture to solve the vehicle routing problem. The user interfaces and the solving mechanism of the system are based on the elements emerged from the hierarchy abstraction.

The two main components of the system are a solving mechanism based on constraint programming techniques and an ecological interface design that allows the user to interact with the system. The human could participate in the modeling and also in the solving phase of the problem through the ecological interface (Figure 2).

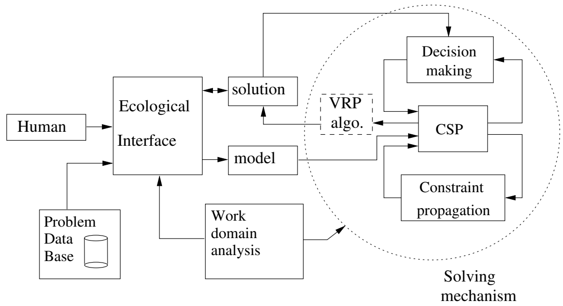


Fig. 2. Decision support system

Before the description of the user interfaces, let us briefly describe the proposed solving mechanism. The solving mechanism is based on constraint programming mixed with specific VRP algorithms. The constraint programming allows us to consider separately the formal definition of the problem (Constraint Satisfaction Problem), analysis mechanisms (propagation techniques), and the solving itself. In our case, we use the propagation techniques to allow discarding the not feasible solutions, whilst the human and the specific algorithms make the decisions to construct a solution.

Besides the solving algorithms, we propose to use model inversion techniques based on classification methods and data analysis in order to offer a support for constraint relaxation, when the problem becomes infeasible (Gacias et al., 2010).

After the analysis of the process to construct a solution for each of the planners of two different security transportation companies, we decided to divide the solving system in three independent phases: the vehicle selection, the customer allocation, and the routes creation. The strategy analysis is one of the steps proposed by Vicente (1999a) after the abstraction hierarchy in order to design more efficient systems. We propose the decomposition in order to facilitate some of the planner sub-tasks depending of the strategy used to solve the problem. It also allows to propose algorithms and graphical tools specific for these sub-tasks. The decomposition does not limit in any case the user strategy.

Both companies follow a similar process:

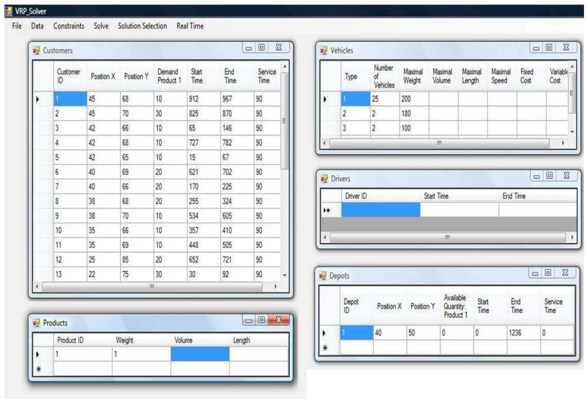
- The customers are already grouped geographically, each group is considered as a route. The number of groups is determined by the experience of the planners or the available vehicles.
- Every working day the customers that have to be served this day are activated.
- The planners check that the routes are balanced and that each route is feasible.
- If necessary, the planners balance the routes or add new ones.
- One of the companies has at it disposal a solver to determine the order of the customers for each route. In the second one, the order is partially proposed and the drivers has to make some decisions.

The three-phase decomposition can be useful because it is suited for multiple possible planner strategies. Besides, our system allows a global optimization of the problem and a local optimization for each phase. Each phase is provided of different control modes to solve the problem. That way, the user can choose the level of automation for each phase according to the relevance of the decisions. Also specific algorithms are proposed for each of the phases.

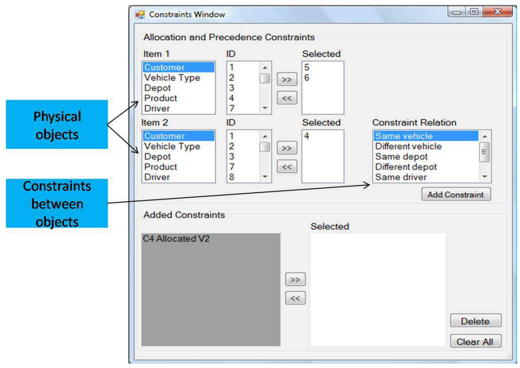
Once the solving mechanism has been described, we present the user ecological interfaces proposed. An Ecological Interface (Vicente, 1999b, 2002) is an interface capable to represent the abstraction hierarchy as an external mental model for the problem solving. The physical and the functional information are displayed for the interface in order to make constraints and complex relationships in the work environment perceptually obvious to the user. This allows more of users' cognitive resources to be devoted to higher cognitive processes such as problem solving and decision making. By reducing mental workload and supporting knowledge-based reasoning, ecological interface aims to improve user performance and overall system reliability for both anticipated and unanticipated events in a complex system.

3.1 Problem modeling interfaces

Two different interfaces are proposed for the problem modeling (see Figure 3). The first interface is based on the physical levels of the abstraction hierarchy. The user can manipulate the physical objects and the information related to each object (physical characteristics and the constraints introduced by the objects). In the second interface, the user can define, describe and manipulate the constraints between the physical objects. The flexibility of the interfaces allows an easy modeling of the problem using an understandable and natural language for the users.



(a) User interface for information on the physical objects



(b) User interface for the physical objects constraints

Fig. 3. Problem modeling user interfaces

3.2 Solving problem interfaces

The solving phase are divided in three independent stages: vehicle selection, customer allocation, and route creation. The system presents a dedicated interface for each of the phases. The interfaces support three control modes (advisory, supervisory, and interactive) to solve each stage of the problem. Then, the user disposes of the tools to construct a solution with the support of an algorithm that check its feasibility. The user has also available efficient algorithms to automatically generate a solution, which can be modified if it is suitable. Finally, the user can propose a partial solution according to his preferences and then let the algorithm complete it. This control mode allows the user to use his know-how and experience to construct a solution, otherwise this kind of requirements can not be satisfied by an algorithm.

The vehicles selection phase is used to determine the vehicles to use to solve the problem (Figure 4).

Fig. 4. User interface for the vehicle selection

The system allows the user to propose and check the feasibility of a solution for the vehicles to use. The interface provides clear information about capacity satisfaction. In some cases, a chosen solution for the vehicle selection is not feasible. The DSS displays the margin of constraint satisfaction, thus the user has pieces of information about the problem feasibility and the flexibility of the solution. An algorithm to compute solutions with a minimum number of vehicles is also proposed, the user has to select the most suitable choice. This algorithm is also used to complete a partial solution proposed by the user.

In the customer allocation phase, we determine for each customer the vehicle to be allocated. Figure 5 displays the user interface for the customer allocation; the customer and vehicle information is easily accessible and the DSS offers to the user the possibility to make or to modify any decision. The system supports the advisory, the supervisory and the interactive control modes.

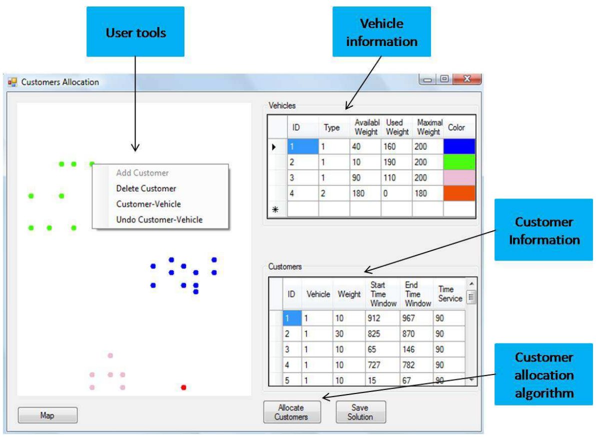
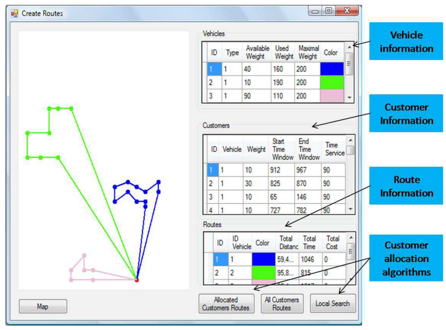


Fig. 5. User interface for the customer allocation

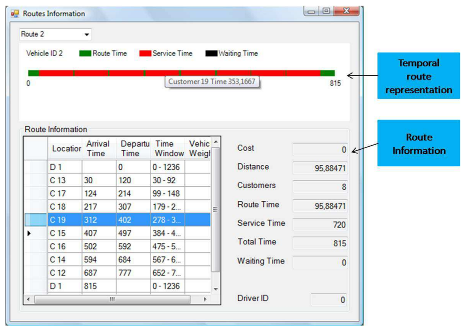
The system uses an algorithm to do the customer allocation. It is also possible to manually allocate the customers on vehicles; in this case the feasibility of each decision is checked by the system. Thus, the user can propose the allocation for some customers and the algorithm complete the solution taking into account the decisions already made by the user.

The sequence of customers for each vehicle is determined in the route creation phase. Like for the customer allocation, all the necessary information are available for the user. Figure 6 shows the proposed user interface. The user disposes of the tools to create the routes and as for the other phases of resolution an algorithm check for the feasibility of the solution.

The algorithms proposed consist of an heuristic that proposes a fast solution keeping an acceptable level of quality and a local search algorithm for a global optimization of the problem. As for the other phases, the user can modify the proposed solutions and can make some decisions in order to obtain a solution that satisfy certain requirements or preferences.



(a) Route creation interface



(b) Temporal route representation interface

Fig. 6. User interfaces for route creation

The system proposes two ways for representing the routes. The representation of the main interface (Figure 6) which is a spatial representation, allows the user to visualize the route on the map and the most important information. A temporal-based representation completes the information. This interface allows to compare and evaluate the characteristics of the routes.

3.3 Solution selection interface

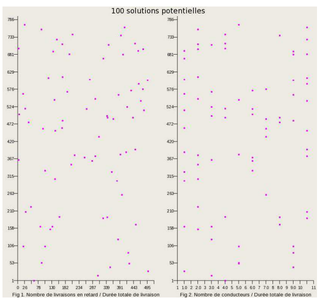
The system offers the possibility to store the final solutions in a list of solutions. An interface to help the user to evaluate and compare the solutions in order to pick the most suitable for the problem is proposed.

The interface consists in a graphical tool in which the solutions are represented in bidimensionals graphs. The number of graphs and the axes are selected by the user depending on the selection criteria, this fact allows to consider side-criteria or user preferences for the solution selection. The interface allows a better display of the solution properties, which facilitates the comparison between them in order to find the solution with the best trade-off.

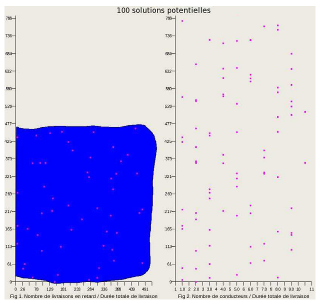
The solution selection works as follows:

- The user define the graph(s) taking the main criteria as the axes of the graphs. For example, in Figure 7 (a) two graphs are represented. The x-axis represents the number of delayed deliveries and the number of vehicles used in the solution for the first and the second graph, respectively. The y-axis represents the makespan of the solution in both graphs.
- The solutions of the problem are represented by points in the different graphs. That way, the user can compare the quality of the solutions for each pair of selected criteria.
- In one of the graphs, the user can select (or discard) the set of solutions that reach (or do not reach) a certain level of quality for the criterion of the graph. For example, in Figure 7 (b) the solutions with a makespan smaller than a limit are considered as acceptable solutions. In Figure 7 (c) the solutions that uses a number of vehicles greater than a limit are discarded by the user.
- The decision to keep or to discard the solutions is propagated to the other graphs. The non-selected solutions are suppressed from the graphs.
- This process is repeated until the solution with the best trade-off between the considered criteria is reached (Figure 7 (d)).

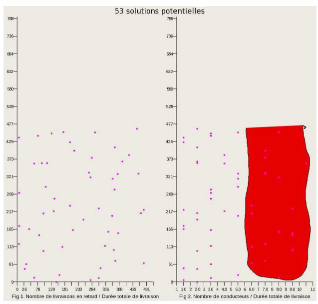
Figure 7 displays the interfaces of the process; (a) the list of solutions represented in two graphs, (b) the selection (blue area) or (c) the discard (red area) of the solutions depending of the evaluation for the selected criteria and (d) the most suitable solution is reached at the end of the process.



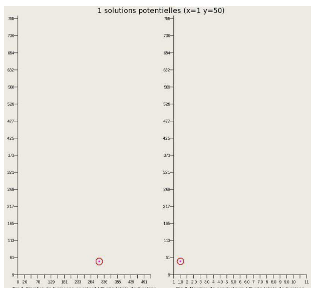
(a) Graphs displaying the solutions of the list



(b) Selection of the interesting solutions (blue area)



(c) Discard the not interesting solutions (red area)



(d) Graphs with the most interesting solution

Fig. 7. User interface for solution selection

4. EXPERIMENTAL STUDY

We proceed to an experimental study in order to validate the mock-up of the interface designed for facilitating the selection of a solution (Figure 7). More precisely, the objective of the experiments was to evaluate the efficiency and the influence on the user of the interface and the interaction mode. The comparison was done with regards to efficiency, *i.e.*, the relationship between mental workload (the mental cost of interacting with the interface) and performance (the ability of the user to select the most efficient solution).

During a Master in Ergonomics and Human Factors, ten students were working for a small transportation company. They spent nine months working for this company on different tasks related to transport and routing. At the end of their training, we asked to each of them to solve different routing problems related to those they already knew.

Each participant had to solve three different routing problems, each of them according to two different interfaces (the interfaces were presented in a random order). The first interface displayed each routing solution separately and consisted in presenting for each solution the routes and performance criteria (costs, number of drivers, and so on). The second interface is the one displayed in Figure 7, implying that all solutions are simultaneously available on the screen. Each graph of this interface presented the performance of the routes on the different criteria. As previously noted, we measured mental workload and performance. Mental workload was assessed with a subjective rating (NASA-TLX rating scale). Performance was considered in relation with the number of correct solutions, *i.e.*, the selected solution was the optimal solution in relation with the current criteria.

Results indicate that mental workload was higher for the second interface (7.07 on average; standard error: 2.02) than for the first one (1.01 on average; standard error: 1.88). Conversely, performance was higher for the second interface (100% of correct solutions) than for the first one (82% of correct solutions on average).

The results seem to stress that the second interface is more efficient than the first one. Although the mental workload was higher it was probably justified by an increased analysis of the solutions presented simultaneously on screen. The first interface did not allow for such an overall analysis of solutions. This first interface then saved participants mental workload but finally lead to a lower performance. Indeed, more detailed statistical analyses are still mandatory to validate these claims.

5. CONCLUSIONS

In this paper, we have proposed a work domain analysis using an abstraction hierarchy for the vehicle routing problem. The objects of the problem and the complex inter-relations between them have been identified. We have proposed an architecture for a generic decision support system based on the elements emerged from the analysis.

We have presented the ecological interfaces of the decision support system for each of the necessary process to solve the problem: modeling phase, solving phase, and solution selection.

The solution selection interface has been part of an experimental study. From the experiments, we can deduce that the interface is more efficient (for the goal-based scenario) than other possible interfaces that we could imagine for the selection of the solution. However, the efficiency decreases for the constraint-based scenario. We can explain this result by the fact that the proposed interface does not display the information about the physical levels of the hierarchy. However, the proposed interface offers the advantage to keep being functional and efficient when we consider the selection of the solution between a larger number of solutions.

In the future, we plan to experiment with the rest of the interfaces proposed for the system in order to study their relevance for the system. We also plan to work on a computer tool allowing to take into account the physical levels of the abstraction hierarchy for the solution selection interface. The user has to be able to represent the solutions on a graph where the axes specify any information about the solution, for example if one specific worker is included in the solution or if one route is used. The interface has to be able to display criteria about not only functional information, but also physical information.

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