A Tangible Collaborative Decision Support System for Various Variants of the Vehicle Routing Problem

Nikolaos Ploskas[1]*, Ioannis Athanasiadis[2], Jason Papathanasiou[3], and Nikolaos Samaras[4]

[1] University of Macedonia, 156 Egnatia Str., Thessaloniki 54006, Greece, ploskas@uom.gr,
[2] Hellenic Open University, 8 Ptolemaion Str., Kozani 50100, Greece, g-athan@hotmail.com,
[3] University of Macedonia, 156 Egnatia Str., Thessaloniki 54006, Greece, jasonp@uom.gr,
[4] University of Macedonia, 156 Egnatia Str., Thessaloniki 54006, Greece, samaras@uom.gr

Abstract. The Vehicle Routing Problem (VRP) is a well-known combinatorial optimization problem where a number of customers must be served with a fleet of vehicles. The classical variation of the VRP is the Capacicated Vehicle Routing Problem (CVRP) with the additional constraint that each vehicle must have uniform capacity. Many Decision Support Systems (DSS) have been implemented to solve real life problems of the VRP and its' variants, but they do not allow multiple decision makers to explore several scenarios of a given problem simultaneously and collaborate with each other in order to find the best possible solution. In this paper, we extend our previous work [35] and incorporate in our spatial DSS four variants of the CVRP: (i) Distance Constrained Vehicle Routing Problem (DVRP), (ii) Vehicle Routing Problem with Time Windows (VRPTW), (iii) Vehicle Routing Problem with Backhauls (VRPB), and (iv) Vehicle Routing Problem With Pickup and Delivery (VRPPD). This extension allows decision makers to solve specific routing problems according to their needs. The proposed collaborative spatial DSS allows two decision makers to collaborate with each other in order to find the best possible solution through a tangible interface. The locations are added though interactive Google Maps and other parameters through user-friendly forms that can be manipulated via tangible interfaces. The proposed DSS has been implemented using Java, TUIO protocol, jsprit, and Google Maps.

Key words: Decision Support Systems, Capacitated Vehicle Routing Problem, Tangible User Interface, Geographical Information Systems, Tabletop Display

* Corresponding author

1 Introduction

The Vehicle Routing Problem (VRP) is a well-known combinatorial optimization problem in the fields of transportation, distribution and logistics [24] [46]. VRP has been initially introduced by Dantzig and Ramser [10]. In the classical VRP, a fleet of vehicles, which are located at a central depot, must deliver a given quantity of products to a number of customers. The objective is to determine the optimal route for a number of vehicles that will serve all customers (and each customer will be served only once) by minimizing the overall transportation cost. The majority of the real world problem are more complex than the VRP. So, many variants of the VRP have been proposed. The Capacitated Vehicle Routing Problem (CVRP) is the most classical variant of the VRP adding an additional constraint that each vehicle must have uniform capacity. As shown in Figure 1, the most well-known variants of the CVRP are: (i) Distance Constrained Vehicle Routing Problem (DVRP), (ii) Vehicle Routing Problem with Time Windows (VRPTW), (iii) Vehicle Routing Problem with Backhauls (VRPB), and (iv) Vehicle Routing Problem With Pickup and Delivery (VRPPD).

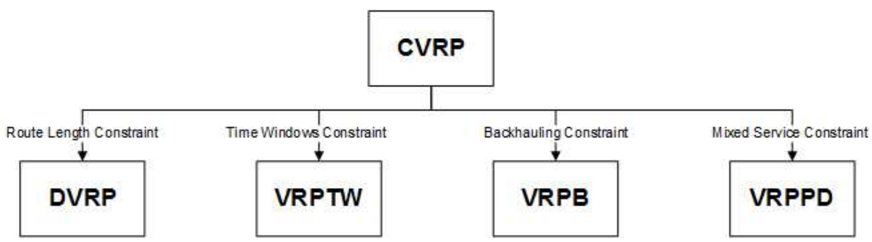

Fig. 1: CVRP variants

Many Decision Support Systems (DSS) exist for the solution of real life problems of the VRP and its' variants. Only few of them integrate real-life geographical information [2] [18] [19] [37] [39] [44]. Anderson et al. [1] used tangible interfaces for the solution of the CVRPTW through a tabletop display. In our previous paper [35], we proposed a collaborative spatial DSS for the CVRP on a tabletop display. In this paper, we extend our previous paper [35] and incorporate in our spatial DSS four variants of the CVRP: (i) DVRP, (ii) VRPTW, (iii) VRPB, and (iv) VRPPD. Our previous experience [35] showed that decision makers need to solve specific routing problems, so the addition of these variants will offer them the opportunity to solve their routing problems by representing the real market and not making any abstractions. The proposed collaborative spatial DSS allows two decision makers to collaborate with each other in order to find the best possible solution through a tabletop display.

The structure of the paper is as follows. Section 2 briefly presents the mathematical form of the CVRP and its' four aforementioned variants. Section 3 presents some key features about the tangible user interfaces, while in Section 4 the analysis and implementations steps of the collaborative spatial DSS are presented. Finally, the conclusions of this paper are outlined in Section 5.

2 Problem Specification

The classical variation of the VRP is the CVRP. The CVRP is the generalization of the Traveling Salesman Problem (TSP), where the products are to be delivered to a number of customers by a fleet of identical vehicles starting and ending at a central depot. The objective is to determine a viable route schedule, which minimizes the distance or the total cost with the following constraints:

– Each vehicle starts and ends its route at the central depot.
– Each customer should be served once by one vehicle.
– The total demand of each route must not exceed the capacity of each vehicle.

Let us assume that the central depot is node 0 and N customers are served by V vehicles. The demand of customer i is d_i and the capacity of vehicle v is c_v. The cost traveling from customer i to customer j by vehicle v is C_{ij}^v. The mathematical form of this problem based on the formulation given by Bodin et al. [5] can be formulated as follows [35]:

$$min \sum_{v=1}^{V} \sum_{i=0}^{N} \sum_{j=0}^{N} C_{ij}^v X_{ij}^v \tag{1}$$

subject to

$$X_{ij}^v = \begin{cases} 1, \text{ if vehicle v travels from customer i to j} \\ 0, \text{ otherwise} \end{cases} \tag{2}$$

$$\sum_{v=1}^{V} \sum_{i=0}^{N} X_{ij}^v = 1, \text{ j} = 1, 2, ..., \text{N} \tag{3}$$

$$\sum_{v=1}^{V} \sum_{j=0}^{N} X_{ij}^v = 1, \text{ i} = 1, 2, ..., \text{N} \tag{4}$$

$$\sum_{i=0}^{N} X_{it}^v - \sum_{j=0}^{N} X_{tj}^v = 0, \text{ v} = 1, 2, ..., \text{V and t} = 1, 2, ..., \text{N} \tag{5}$$

$$\sum_{j=0}^{N} c_j \left(\sum_{i=0}^{N} X_{ij}^v \right) \leq c_v, \text{ v} = 1, 2, ..., \text{V} \tag{6}$$

$$\sum_{i=1}^{N} X_{0j}^v \leq 1, \text{ v} = 1, 2, ..., \text{V} \tag{7}$$

$$\sum_{j=1}^{N} X_{i0}^{v} \leq 1, \text{ v = 1, 2, ..., V} \tag{8}$$

Objective function (1) refers to the minimization of the total cost. Constraint (2) ensures that the variable X_{ij}^{v} takes the integer 0 or 1. Constraints (3) and (4) ensure that each customer is served once, while Constraint (5) ensures the route continuity. Constraint (6) ensures that the total demand of each route will not exceed the capacity of each vehicle, while Constraints (7) and (8) ensure that each vehicle is used only once.

Exact and heuristic algorithms exist for the solution of the CVRP. In the first category, branch-and-cut methods [4] [29] and the branch and-cut-and-price algorithm proposed by Fukasawa et al. [14] have been proposed (for a detailed survey of exact algorithms for the CVRP, see [32] [47]). In the second category, many heuristics and metaheuristics have been proposed (for a detailed survey of approximate algorithms for the CVRP, see [7] [27]).

The following sub-sections of this section present the four variants of the CVRP that are incorporated in our proposed DSS: (i) DVRP, (ii) VRPTW, (iii) VRPB, and (iv) VRPPD.

2.1 Distance Constrained Vehicle Routing Problem

The DCVRP is a variant of the CVRP adding the following constraint: the total length of each route must not exceed a fixed length. Based on the previous formulation, let us denote with L_v the maximum allowed total length of the route served by vehicle v. Then, one more constraint, which refers to the maximum allowed fixed length of each route, should be added to the formulation of the CVRP in order to represent the DCVRP variant:

$$\sum_{i=0}^{N}\sum_{j=0}^{N} d_{ij}^{v} X_{ij}^{v} \leq L_v, \text{ v = 1, 2, ..., V} \tag{9}$$

Exact and heuristic algorithms exist for the solution of the DCVRP. In the first category, the algorithms proposed by Laporte, Nobert, & Desrochers [25] [26] exist. In the second category, many heuristics and metaheuristics have been proposed (for a detailed survey of exact approximate algorithms for the DCVRP, see [46]).

2.2 Vehicle Routing Problem With Time Windows

The VRPTW is a variant of the CVRP adding the following constraints: (i) the service of each customer i starts within a time window $[e_i, l_i]$, and (ii) each vehicle v stops for s_i time instants in order to serve customer i. In case of early arrival to a customer i, the vehicle waits until the service time, i.e. until time instant e_i.

Exact and heuristic algorithms exist for the solution of the CVRP. In the first category, the algorithms proposed by Cook & Rich [9], Kallehauge, Larsen, Madsen

[20], Kohl et al. [22], and Larsen [28]. In the second category, many heuristics [17] and metaheuristics [36] [43] have been proposed (for a detailed survey of exact and approximate algorithms for the VRPTW, see [46]).

2.3 Vehicle Routing Problem With Backhauls

The VRPB is a variant of the CVRP where the N customers are partitioned into two subsets: (i) the first subset, L, contains l Linehaul customers that require a given quantity of products to be delivered, and (ii) the second subset, B, contains b Backhaul customers that require a given quantity to be picked up. The VRPB alters the third constraint of the CVRP, i.e. the total demand of each route must not exceed the capacity of each vehicle, in the following manner: the total demand of the linehaul and backhaul customers visited in a route do not exceed separately the vehicle capacity. Furthermore, the VRPB adds the following constraint: all deliveries must be made on each route before any pickup can be made.
Exact and heuristic algorithms exist for the solution of the CVRP. In the first category, the algorithms proposed by Mingozzi, Giorgi, & Baldacci [30], and Toth & Vigo [45]. In the second category, many heuristics have been proposed [6] [11] [15] (for a detailed survey of exact and approximate algorithms for the VRPB, see [46]).

2.4 Vehicle Routing Problem With Pickup and Delivery

The VRPPD is a variant of the CVRP where customers can also return a given quantity of products. Each customer i is associated with two quantities: (i) d_i denotes the demand of customer i, and (ii) p_i denotes the quantity of products that is picked up at customer i. Let us denote with O_i the node that is the origin of the delivery quantity and D_i the node that is the destination of the pickup quantity. These nodes, O_i and D_i may be the central depot; in this case, the customer will be served from products in stock or the products picked up at the customer will return to the central depot, respectively. If this is not the case, then a given quantity of products that are picked up from customer O_i can be delivered to customer i and a given quantity of products picked up at customer i can be delivered to customer D_i. The VRPPD alters the third constraint of the CVRP, i.e. the total demand of each route must not exceed the capacity of each vehicle, in the following manner: the current load of each vehicle along a route must be non-negative and must not exceed the capacity of the vehicle. Moreover, the VRPPD adds the following constraints: (i) Each customer O_i, when different from the central depot, must be served in the same route and before customer i, and (ii) Each customer D_i, when different from the central depot, must be served in the same route and after customer i.
Exact and heuristic algorithms exist for the solution of the VRPPD. In the first category, the algorithms proposed by Dumas, Desrosiers, & Soumis [12], Ruland and Rodin [38], and Savelsbergh & Sol [40]. In the second category, many heuristics have been proposed [33] [49] (for a detailed survey of exact and approximate algorithms for the VRPB, see [46]).

3 Tangible User Interfaces

A tabletop is a horizontal multi-gesture user interface surface that provides co-location and interaction for single and multiple user [31] and is a useful shared space for diverse collaborative tasks [50]. Traditional input devices can be replaced by a tabletop display. By utilizing a tabletop display, users can interact with more natural devices. A tabletop can be handled by: (i) finger, (ii) hand gestures, and/or (iii) controller objects. In this paper, we use all these approaches; decision makers can specify customers' locations using controller objects and more specifically fiducials and can input/alter other parameters through finger and hand gestures.
Tabletop displays have been widely used in decision-making process. Kientz et al. [23] proposed a DSS to support collaborative decision-making for home-based therapy teams. Scotta et al. [42] presented a multi-user tangible interface system that aims at introducing an instrument to improve the response phase of the decision-making process. Hofstra et al. [16] used multi-user tangible interfaces for decision-making in disaster management. Scott et al. [41] have used tabletop interfaces to support collaborative decision-making in maritime operations. Engelbrecht et al. [13] used digital tabletops for situational awareness in emergency situations. Ploskas et al. [34] proposed an interactive spatial DSS with tangible user interfaces through a tabletop that supports decision-making and integrates geographical information data in the DSS for the Multiple Capacitated Facility Location Problem. The proposed paper uses the same tabletop interface with our previous work [34], but solves another problem (four CVRP variants) and uses different collaborative strategies. Finally, in our previous work [35], we proposed a collaborative spatial DSS for the CVRP on a tabletop display that allows two decision makers to collaborate with each other in order to find the best possible solution. This paper is an extension of our previous work [35] and incorporate in our spatial DSS four variants of the CVRP.
The tabletop used in this paper has been designed and constructed from scratch. The key design features are thoroughly described in [3].

4 Design, Implementation and Presentation of the Collaborative DSS

Figure 2 presents the decision making process that the decision makers can perform using the DSS. Initially, the decision makers select the type of the problem among five variants of the VRP: (i) CVRP, (ii) DVRP, (iii) VRPTW, (iv) VRPB, and (v) VRPPD. In the previous step, a small description of the five variants is presented in order for the decision makers to understand the implications of the selection. Then, the decision makers select the location of the central depot via an interactive Google Map using fiducials on the tabletop. In the next step, the decision makers select the location of the customers and for each customer input the model data (e.g. demand, service time, etc.) depending on the variant that they selected (Figure 3). When the market is large and the manual integration of the data is not convenient, decision makers can download an Excel template, incorporate their data and upload the Excel file to the DSS. After this step the final representation of the problem is presented to the decision makers. Then, the tabletop display is divided into two segments, where each decision maker can input different model parameters (i.e. number of vehicles, vehicles' capacity, fixed cost, and cost per km) and find a solution (Figure 4). The solution is visualized through a Google Map and the decision maker can export a detailed report as a pdf file. Furthermore, one decision maker can press the share button in order to copy his/her model parameters and solution to the other decision maker's display. When the share button is pressed, the current solution is saved as the current best possible one. Figures 3 and 4 show the process of the solution of a VRPTW; similar steps are followed on the other VRP variants.

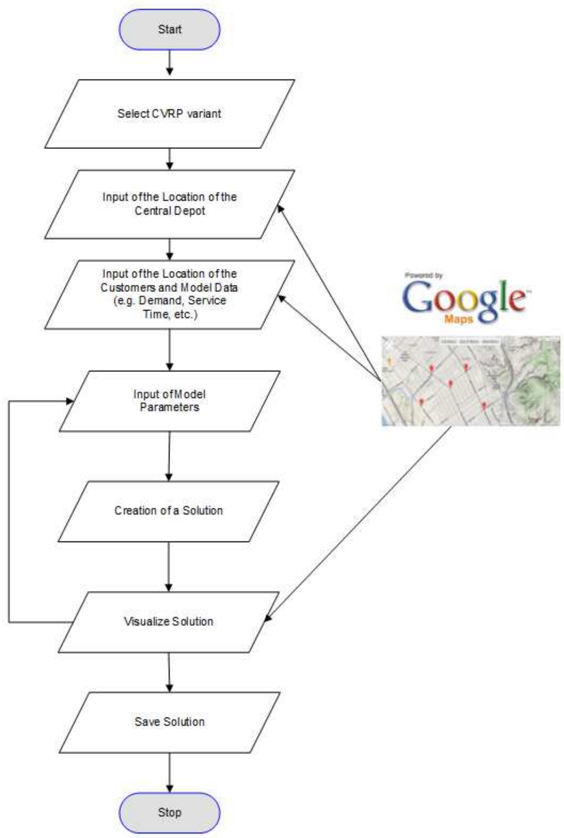

Fig. 2: Decision Making Process

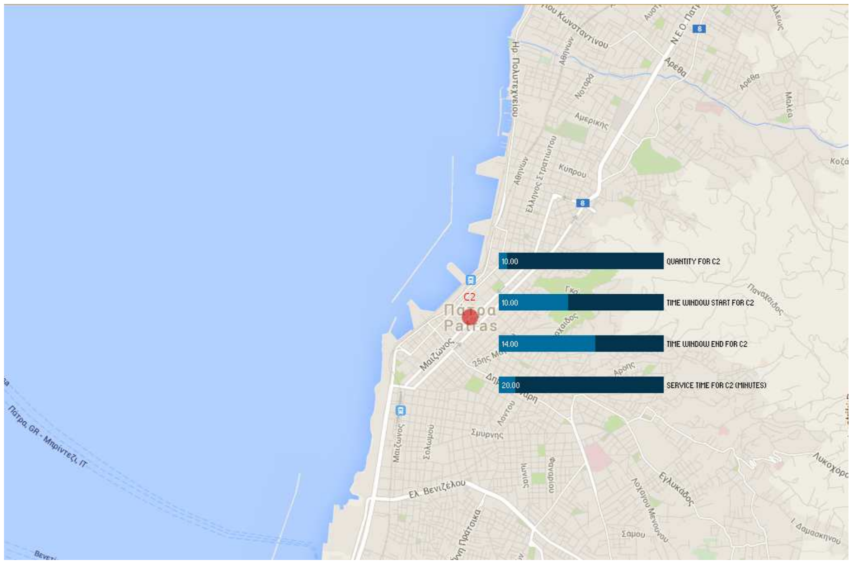

Fig. 3: Select Customer's Location and Input Demand Quantity, Service Time Start, Service Time End, and Service Time for the Customer (in VRPTW variant)

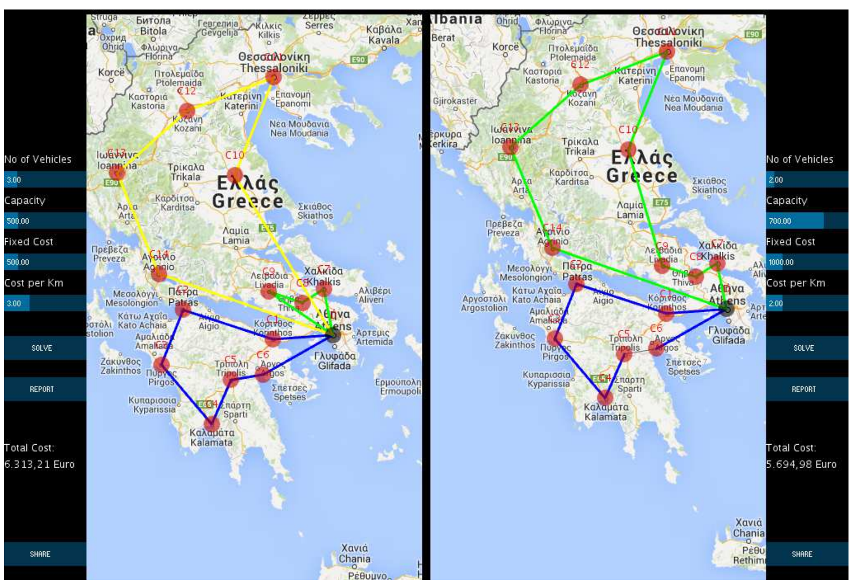

Fig. 4: Visualization of the Solutions

The spatial DSS has been implemented using Java, TUIO, jsprit and Google Maps. More specifically, the open source TUIO protocol [21] has been used for the recognition of a set of objects with fiducials and draw gestures onto the table surface with the finger tips. Moreover, jsprit [19], a java based, open source toolkit for solving rich traveling salesman (TSP) and VRP variants, has been utilized in order to find a solution for the given problems.
Community Core Vision (CCV), previously known as tbeta, is an open source software that takes as input a video stream and outputs several tracking data, such as coordinates of the objects or events like finger down [8]. The recognition of the camera from CCV requires the installation of the device driver named CL-EYE Platform Driver. Moreover, open source Unfolding library [48] for Java was used to create interactive Google Maps and geovisualizations. The library supports various functions to get automatically the distance in km between two points in the earth.

5 Conclusions

The CVRP is the classical variant of the VRP, which is a well-known combinatorial optimization problem with many practical applications. In this paper, we extend our previous work [35] and propose a collaborative spatial DSS that allows two decision makers to collaborate with each other in order to find the best possible solution of a given CVRP and its' four well-known variants: (i) DVRP, (ii) VRPTW, (iii) VRPB, and (iv) VRPPD. The addition of these variants to the DSS allows decision makers to solve their routing problems by representing the real market and giving the actual constraints and not making any abstractions. Decision makers can initially locate the customers through interactive and user-friendly Google Maps and experiment with the problem's parameters to explore various solutions. Then, they can compare their solutions and find the best possible one. In future work, we plan to evaluate the proposed DSS and compare it with a standard non–tangible solution.

References

1. Anderson, D., Anderson, E., Lesh, N., Marks, J., Mirtich, B., Ratajczak, D., Ryall, K.: Human-guided simple search. In: Seventeenth National Conference on Artificial Intelligence Conference Proceedings (AAAI-00), 209–216 (2000)
2. ArcGIS: http://www.esri.com/software/arcgis. Last access on 4/10/14.
3. Athanasiadis, I.: Analysis, Design and Implementation of a Hybrid System for Teaching Basic Programming Structures using Traditional and Tangible User Interfaces to Pre Teenagers. MSc Thesis, School of Science & Technology, Hellenic Open University (2014)
4. Blasum, U., Hochstttler, W.: Application of the branch and cut method to the vehicle routing problem. Technical Report zaik2000-386, Zentrum fur Angewandte Informatik Koln (2000)

5. Bodin, L., Golden, B.L., Assad, A., Ball, M.O.: The state of the art in the routing and scheduling of vehicles and crews. Computers & Operations Research 10, 69–221 (1983)
6. Clarke, G., Wright, J.V.: Scheduling of vehicles from a central depot to a number of delivery points. Operations Research 12, 568–581 (1964)
7. Cordeau, J. F., Gendreau, M., Hertz, A., Laporte, G., Sormany, J. S.: New heuristics for the vehicle routing problem. Springer, 279–297 (2004)
8. Community Core Vision: http://nuicode.com/projects/tbeta. Last access on 4/10/14.
9. Cook, W., Rich, J.L.: A parallel cutting plane algorithm for the vehicle routing problem with time windows. Technical report, Computational and Applied Mathematics, Rice University, Houston, TX (1999).
10. Dantzig, G. B., Ramser, R.H.: The truck dispatching problem. Management Science 6, 80–91 (1959)
11. Deif, I., Bodin, L.D.: Extension of the clarke and wright algorithm for solving the vehicle routing problem with backhauling. In: A. Kidder (Ed.), Proceedings of the Babson College Conference on Software Uses in Transportation and Logistic Management, Babson Park, MA, 75–96 (1984)
12. Dumas, Y., Desrosiers, J., Soumis, F.: The pickup and delivery problem with time windows. European Journal of Operational Research 54, 7–22 (1991)
13. Engelbrecht, A., Borges, M., Vivacqua, A. S.: Digital tabletops for situational awareness in emergency situations. In: 15th International Conference Proceedings on Computer Supported Cooperative Work in Design (CSCWD), 669–676 (2011)
14. Fukasawa, R., Longo, H., Lysgaard, J., de Arago, M. P., Reis, M., Uchoa, E., Werneck, R. F.: Robust branch-and-cut-and-price for the capacitated vehicle routing problem. Mathematical programming 106:3, 491–511 (2006)
15. Goetschalckx, M., Jacobs-Blecha, C.: The vehicle routing problem with backhauls. European Journal of Operational Research 42, 39–51 (1989)
16. Hofstra, H., Scholten, H., Zlatanova, S., Scotta, A.: Multi-user tangible interfaces for effective decision-making in disaster management. In: Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters, Springer, 243–266 (2008)
17. Homberger, J., Gehring, H.: Two evolutionary metaheuristics for the vehicle routing problem with time windows. INFOR 37, 297–318 (1999)
18. Ioannou, G., Kritikos, M. N., Prastacos, G. P.: Map-Route: a GIS-based decision support system for intra-city vehicle routing with time windows. Journal of the Operational Research Society, 842–854 (2002)
19. jsprit: https://github.com/jsprit/jsprit. Last access on 4/10/14.
20. Kallehauge, B., Larsen, J., Madsen, O.B.G.: Lagrangean duality and nondifferentiable optimization applied on routing with time windows-experimental results. Internal report IMM-REP-2000-8, Department of Mathematical Modelling, Technical University of Denmark, Lyngby, Denmark (2000)
21. Kaltenbrunner, M., Bovermann, T., Bencina, R., Costanza, E.: TUIO - A Protocol for Table-Top Tangible User Interfaces. In: 6th International Workshop on Gesture in Human-Computer Interaction and Simulation Proceedings (2005).
22. Kohl, N., Desrosiers, J., Madsen, O.B.G., Solomon, M.M., Soumis, F.: 2-Path cuts for the vehicle routing problem with time windows. Transportation Science 33, 101–116 (1999)
23. Kientz, J. A., Hayes, G. R., Abowd, G. D., Grinter, R. E.: From the war room to the living room: decision support for home-based therapy teams. In: 20th Anniversary Conference on Computer Supported Cooperative Work Proceedings, 209–218 (2006)

24. Laporte, G.: Fifty years of vehicle routing. Transportation Science 43:4, 408-416 (2009)
25. Laporte, G., Desrochers, M., Nobert, Y.: Two exact algorithms for the distance-constrained vehicle routing problem. Networks 14, 161–172 (1984)
26. Laporte, G., Nobert, Y., Desrochers, M.: Optimal routing under capacity and distance restrictions. Operations Research 33, 1050–1073 (1985)
27. Laporte, G., Semet, F.: Classical heuristics for the capacitated VRP. In: P. Toth & D. Vigo (Eds.), The Vehicle Routing Problem, SIAM Monographs on Discrete Mathematics and Applications 9:5, 109-128 (2002)
28. Larsen, J.: Parallellization of the vehicle routing problem with time windows. Ph.D. thesis, Department of Mathematical Modelling, Technical University of Denmark, Lyngby, Denmark (1999)
29. Lysgaard, J., Letchford, A.N., Eglese, R.W.: A new branch-and-cut algorithm for the capacitated vehicle routing problem. Mathematical Programming 100:2, 423-445 (2004)
30. Mingozzi, A., Giorgi, S., Baldacci, R.: An exact method for the vehicle routing problem with backhauls. Transportation Science 33, 315–329 (1999)
31. Madni, T.M., Sulaiman, S.B., Tahir, M.: Content-Orientation for Collaborative Learning Using Tabletop Surfaces. In: Proceedings of 2013 International Conference on Information Science and Applications (ICISA), 1–6. IEEE (2013)
32. Naddef, D., Rinaldi, G.: Branch-and-Cut Algorithms for the Capacitated VRP. In: P. Toth & D. Vigo (Eds.), The Vehicle Routing Problem, SIAM Monographs on Discrete Mathematics and Applications 9, 53-84 (2002)
33. Psaraftis, H.N.: k-Interchange procedures for local search in a precedence-constrained routing problem. European Journal of Operational Research 13, 391–402 (1983)
34. Ploskas, N., Athanasiadis, I., Papathanasiou, J., Samaras, N: An Interactive Spatial Decision Support System Enabling Co-Located Collaboration using Tangible User Interfaces for the Multiple Capacitated Facility Location Problem. International Journal of Decision Support System Technology (submitted for publication)
35. Ploskas, N., Athanasiadis, I., Papathanasiou, J., Samaras, N: A Collaborative Spatial Decision Support System for the Capacitated Vehicle Routing Problem on a Tabletop Display. In Decision Support Systems IV - Information and Knowledge Management in Decision Processes. Springer Proceedings in Business Information Processing (submitted for publication)
36. Rochat, Y., Taillard, E.D.: Probabilistic diversification and intensification in local search for vehicle routing. Journal of Heuristics 1, 147–167 (1995)
37. Ruiz, R., Maroto, C., Alcaraz, J.: A decision support system for a real vehicle routing problem. European Journal of Operational Research 153:3, 593–606 (2004)
38. Ruland, K.S., Rodin, E.Y.: The pickup and delivery problem: Faces and branchand-cut algorithm. Computers and Mathematics with Applications 33, 1–13 (1997)
39. Santos, L., Coutinho-Rodrigues, J., Antunes, C. H.: A web spatial decision support system for vehicle routing using Google Maps. Decision Support Systems 51:1, 1–9 (2011)
40. Savelsbergh, M.W.P., Sol, M.: Drive: Dynamic routing of independent vehicles. Operations Research 46, 474-490 (1998)
41. Scott, S. D., Allavena, A., Cerar, K., Franck, G., Hazen, M., Shuter, T., Colliver, C.: Investigating tabletop interfaces to support collaborative decision-making in maritime operations. In: International Command and Control Research and Technology Symposium Proceedings (ICCRTS 2010), 22–24 (2010)

42. Scotta, A., Pleizier, I. D., Scholten, H. J.: Tangible user interfaces in order to improve collaborative interactions and decision making. In: 25th Urban Data Management Symposium Proceedings, 15–17 (2006)
43. Taillard, E.D., Badeau, P., Gendreau, M., Guertin, F., Potvin, J.Y.: A tabu search heuristic for the vehicle routing problem with soft time windows. Transportation Science 31, 170–186 (1997)
44. Tarantilis, C. D., Kiranoudis, C. T.: Using a spatial decision support system for solving the vehicle routing problem. Information & Management 39:5, 359–375 (2002)
45. Toth, P., Vigo, D.: An exact algorithm for the vehicle routing problem with backhauls. Transportation Science 31, 372–385 (1997)
46. Toth, P., Vigo, D.: The vehicle routing problem. Siam (2001)
47. Toth, P., Vigo, D.: Branch-and-bound algorithms for the capacitated VRP. In: P. Toth & D. Vigo (Eds.), The Vehicle Routing Problem, SIAM Monographs on Discrete Mathematics and Applications 9:2, 29-51 (2001)
48. Unfolding: http://unfoldingmaps.org/. Last access on 4/10/14.
49. Wilson, H., Sussman, J., Wang, H., Higonnet, B.: Scheduling algorithms for dialaride systems. Technical Report USL TR-70-13, Urban Systems Laboratory, MIT, Cambridge, MA (1971)
50. Yoshida, S., Yano, S., Ando, H.: Implementation of a tabletop 3D display based on light field reproduction. In: Posters of ACM SIGGRAPH 2010, 61. ACM (2010)