# A Collaborative Spatial Decision Support System for the Capacitated Vehicle Routing Problem on a Tabletop Display

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**Abstract.** The Vehicle Routing Problem (VRP) is a well-known combinatorial optimization problem. The Capacitated Vehicle Routing Problem (CVRP) is a widely studied variant of the VRP. Although many Decision Support Systems (DSS) have been implemented to support decision makers solve real life problems of the VRP and its variants, these systems do not allow multiple decision makers to collaborate with each other and explore different scenarios on a specific problem. Recent advances in hardware and software have enabled a new generation of tabletop displays that can sense multiple inputs from different users at the same time. In this paper, we present 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. The locations of the customers to serve are added using interactive Google Maps. The DSS extracts the geographical information of the selected locations, finds the distances between them and solves the problem. The proposed DSS has been implemented using Java, TUIO protocol, jsprit and Google Maps.

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

## 1 Introduction

The Vehicle Routing Problem (VRP) is a well-studied combinatorial optimization problem in the field of transportation logistics [17] [27]. VRP has been initially introduced by Dantzig and Ramser [8]. Many variants of the VRP have

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been proposed since then. The Capacitated Vehicle Routing Problem (CVRP) is a well-known variant of the VRP and is an NP-hard problem. The objective is to determine a viable route schedule, which minimizes the distance or the total cost, for a number of vehicles starting from a central depot to a number of customers, and then return to the depot. Each customer must be served once by one vehicle and the total demand of any route must not exceed the capacity of the vehicle.

VRP was addressed by many authors and several algorithms and methods were proposed to solve its different variants. The algorithms and methods that have been proposed fall into two categories: (i) exact algorithms, and (ii) approximate algorithms. In the first category, most research focused on developing branch-and-cut methods [4] [18]. Another exact algorithm is the branch and-cut-and-price algorithm proposed by Fukasawa et al. [10] (for a detailed survey of exact algorithms for the CVRP, see [20] [28]). In the second category, many heuristics and metaheuristics have been proposed (for a detailed survey of approximate algorithms for the CVRP, see [6] [16]).

Many software packages and DSS exist for the solution of the VRP and its variants exclusively. Only few of them integrate real-life geographical information of the customers' locations using interactive maps [2] [12] [13] [22] [23] [26]. Anderson et al. [1] used a tabletop display in the solution of the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW). To the best of our knowledge, this is the first paper that proposes a collaborative spatial DSS for the CVRP on a tabletop display. The innovation of this paper is that we implement a collaborative spatial DSS for the CVRP on a tabletop display that can assist decision-makers to collaborate with each other and explore different scenarios on a specific problem.

The structure of the paper is as follows. Section 2 presents some key features about the tangible user interfaces, a brief review of the use of tangible user interfaces on decision-making process and the principles of the constructed tabletop. Section 3 briefly presents the mathematical form of the problem, 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 Tangible User Interfaces

A tabletop is a computing device that offers a large, horizontal digital display and enables one or more users to input commands to the device by interacting directly with the display surface [24]. A tabletop offers a useful shared space for diverse collaborative tasks. The key idea of the tabletop displays is the replacement of the traditional input devices (e.g. mouse, keyboard) with more natural and interactive devices. A tabletop can be handled either by finger and hand gestures or by controller objects. In this paper, we use both approaches; customers' locations are specified using controller objects and more specifically fiducials, and the other parameters are given through finger and hand gestures. Fiducials are markers used to recognize an object. Two types of fiducials exist:

(i) active, (ii) and passive. Passive fiducials are images that can be recognized through a camera. An example of a passive fiducial is shown in Figure 1.

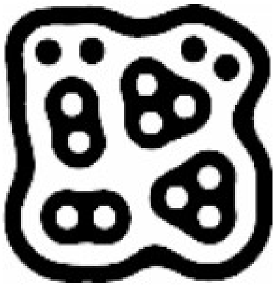


Fig. 1: Example of Passive Fiducial

According to Müller–Tomfelde [19], there will be an increasing adoption of tabletop systems in the next decade. This becomes more evident if we focus on the tabletop's Hype Cycle [19], where we may notice the clear shift to the productivity phase of the technology.

Tabletop displays have been widely used in decision-making process. Kientz et al. [15] proposed a DSS to support collaborative decision-making for home-based therapy teams. Scotta et al. [25] 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. [11] used multi-user tangible interfaces for decision-making in disaster management. Scott et al. [24] have used tabletop interfaces to support collaborative decision-making in maritime operations. Engelbrecht et al. [9] used digital tabletops for situational awareness in emergency situations. In our previous work [21], we used the same collaborative tabletop interface to support decision-making for the solution of the multiple capacitated facility location problem. The proposed paper uses the same tabletop interface with our previous work [21], but solves another problem (VRP) and uses different collaborative strategies.

Most of the aforementioned papers have used commercial tabletop interfaces. The tabletop used in this paper has been designed and constructed from scratch. We designed our own tabletop instead of using a commercial tabletop interface, because commercial tabletop interfaces allow multiple gestures and the use of a pen to draw upon them, but do not support the use of several fiducials for the recognition of different objects in the tabletop interface. Figure 2 shows the interior and the exterior of the designed tabletop.

The most significant constraints and parameters of the construction were:

- The need to support multi–touch and object recognition.
- Its physical characteristics were devised with the aim of promoting collocated collaboration of two decision makers.

- The absence of need for user awareness and shared working space.

The whole system consists of two separate subsystems. The first one refers to the image projection system and the second to the input capturing system (multi–touch and object recognition). The input capturing system uses the infrared light as a means of input identification in order to avoid interference with the image projection. The key design features of this tabletop are (for a more detailed description, see [3]):

- Diffused Surface Illumination (DSI) was used to construct the tabletop, because it recognizes objects and fiducials and there are no illumination hotspots due to the even illumination throughout the surface.
- 85 cm height.
- 42 inches display.
- A sort throw Benq MS612ST projector was used with a throw ratio of 0.90-1.08.
- An endlighten acrylic with infrared leds on each side of it.
- Two modified infrared cameras in a row, supporting 120 fps for $320x240$ resolution and 60 fps for $640x480$ resolution each, with a lens focusing distance of 2.8 mm.

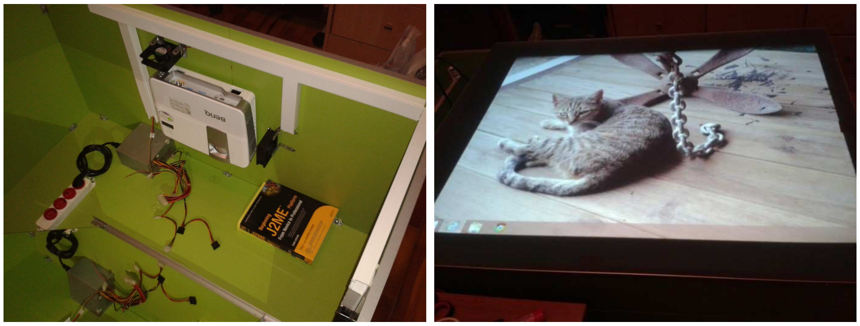

(a) Inside View of the Tabletop (b) Overview of the Tabletop

Fig. 2: The Constructed Tabletop

## 3 Problem Specification

The CVRP can be described as follows: Products are to be delivered to a number of customers by a fleet of identical vehicles starting from 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.
- The total length of each route must not exceed a fixed length.

Let us assume that the central depot is node 0 and $V$ vehicles should serve $N$ customers. Let us denote with $d_i$ the demand of customer $i$ and $c_v$ the capacity of vehicle $v$. The maximum allowed total length of the route served by vehicle $v$ is denoted with $L_v$ and the cost travelling 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:

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

subject to

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

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

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

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

$$\sum_{i=0}^{N} \sum_{j=0}^{N} d_{ij}^v X_{ij}^v \leq L_v, \text{ v = 1, 2, ..., V} \tag{6}$$

$$\sum_{j=0}^{N} c_j \left( \sum_{i=0}^{N} X_{ij}^v \right) \leq c_v, \text{ v = 1, 2, ..., V} \tag{7}$$

$$\sum_{i=1}^{N} X_{0j}^v \leq 1, \text{ v = 1, 2, ..., V} \tag{8}$$

$$\sum_{j=1}^{N} X_{i0}^v \leq 1, \text{ v = 1, 2, ..., V} \tag{9}$$

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. Constraint (5) ensures the route continuity, while Constraint (6) refers to the maximum allowed fixed length of each route. Constraint (7) ensures that the total demand of each route will not exceed the capacity of each vehicle, while Constraints (8) and (9) ensure that each vehicle is used only once.

## 4 Design, Implementation and Presentation of the DSS

Figure 3 presents the decision making process that the decision makers can perform using the DSS. Initially, the decision makers select the location of the central depot via an interactive Google Map using fiducials on the tabletop (Figure 4a). Then, the decision makers select the location of the customers (Figure 4b) and for each customer input the demand quantity and the service time (Figure 5). After this step the final representation of the problem is presented to the decision makers (Figure 6). 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 7). 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.

Let us give an insight to the collaboration procedure that we have adopted in this implementation. Two decision makers can work on the same problem and find alternatives for its solution. At any time, the decision makers can compare their solutions and keep the best one by pressing the share button (Figure 7). Then, decision makers can work to improve the found solution by adjusting the problem's parameters (e.g. editing the number of vehicles or the fixed cost) and explore new alternatives. When a final solution is found for the problem, then the decision makers can press the report button to export a detailed report.

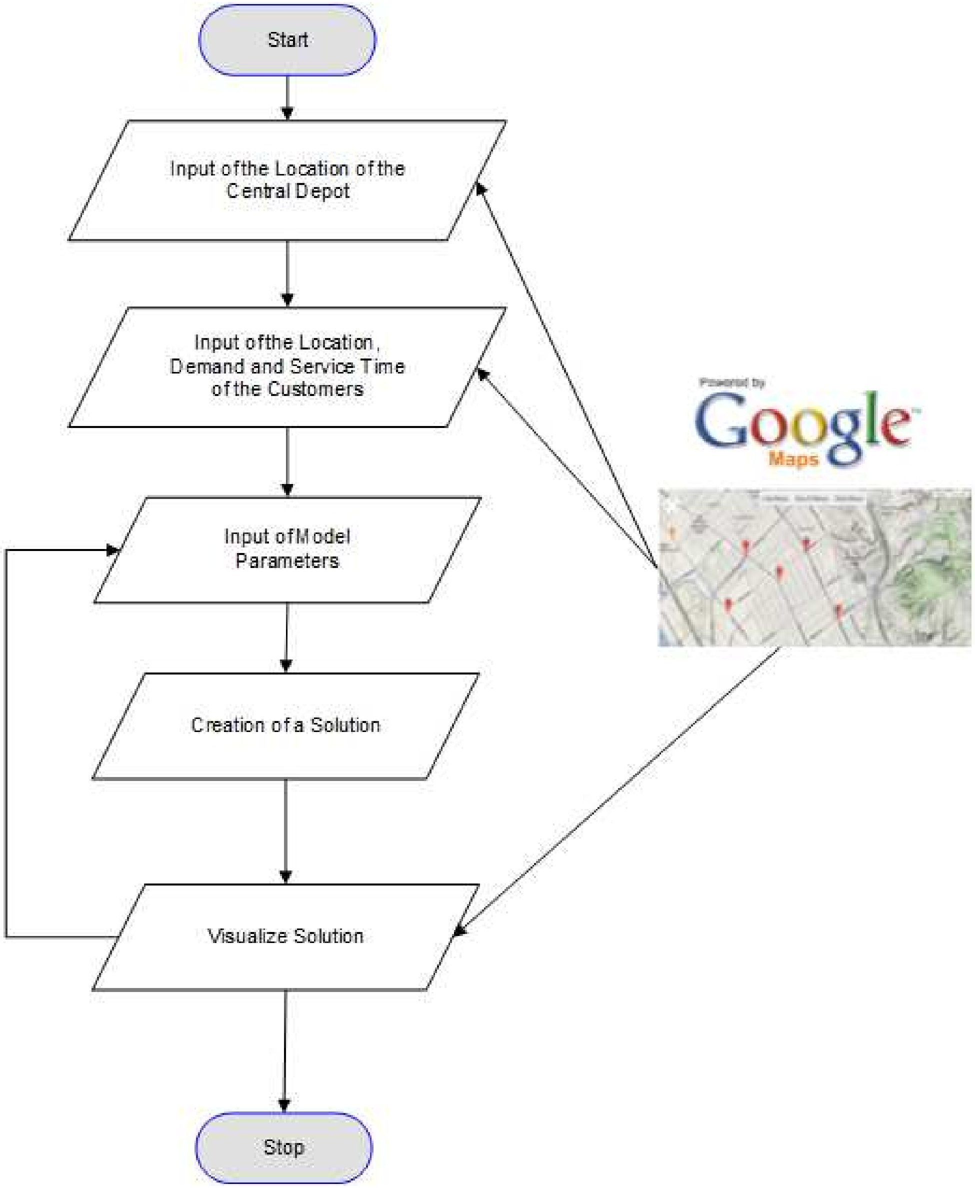
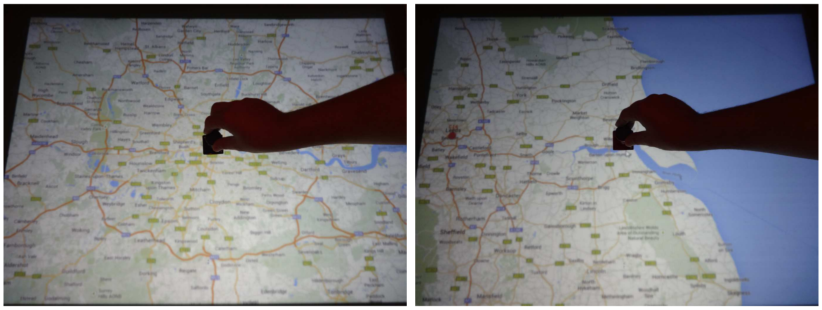


Fig. 3: Decision Making Process



(a) Central Depot Selection (b) Customer Selection

Fig. 4: Locations Selection

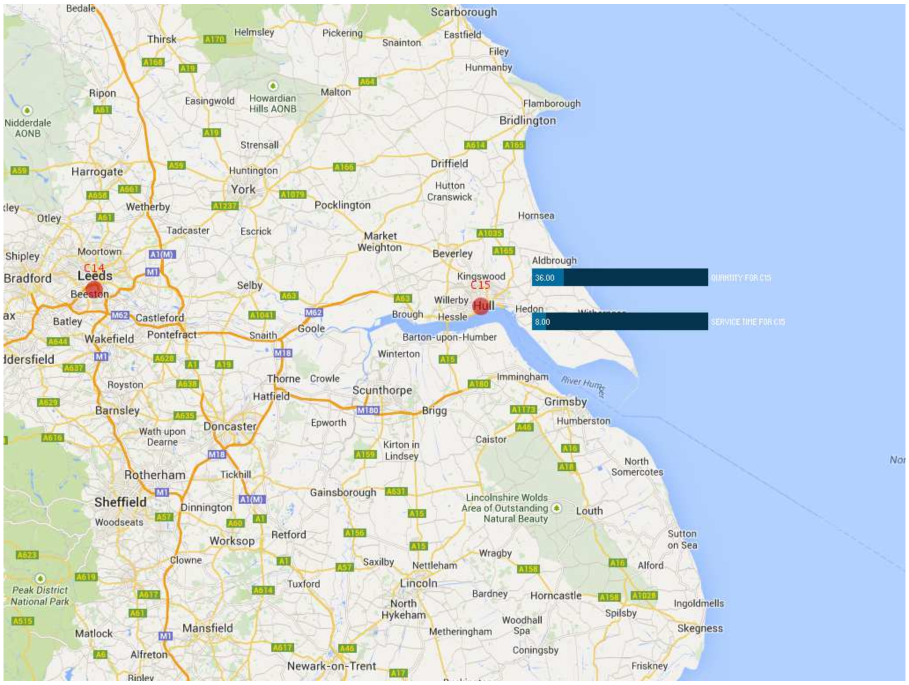
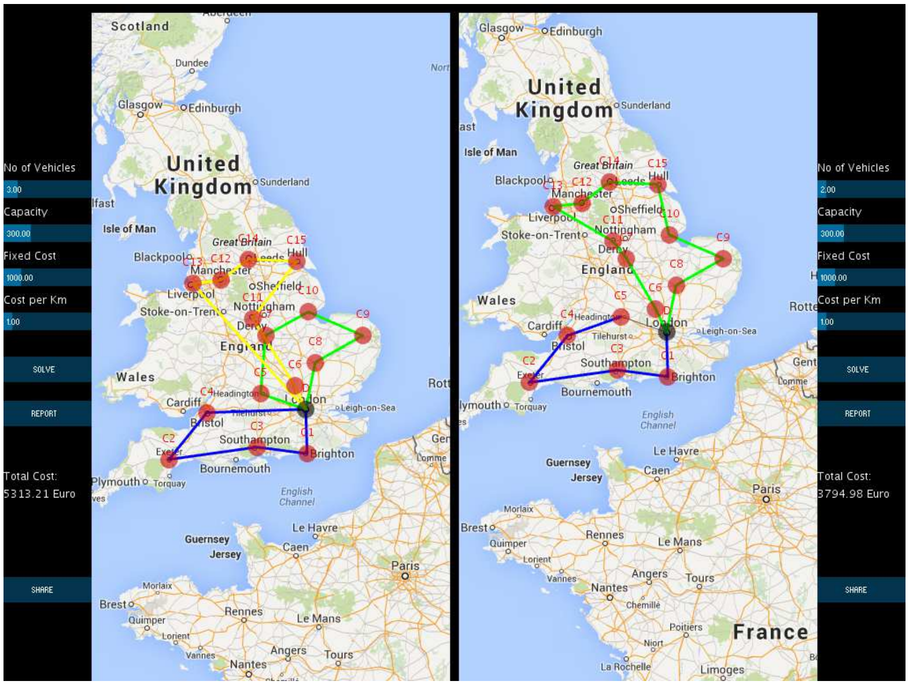


Fig. 5: Input of Demand Quantity and Service Time for each Customer

Fig. 6: Final Representation of the Problem



No of Vehicles
3.00
Capacity
300.00
Fixed Cost
1000.00
Cost per Km
1.00
Total Cost:
5313.21 Euro

No of Vehicles
2.00
Capacity
300.00
Fixed Cost
1000.00
Cost per Km
1.00
Total Cost:
3794.98 Euro

Fig. 7: Visualization of the Solutions

The spatial DSS has been implemented using Java, TUIO, jsprit and Google Maps. More specifically, the open source TUIO protocol [14] has been utilized in order to recognize a set of objects with fiducials and draw gestures onto the table surface with the finger tips. TUIO protocol is encoded using Open Sound Control format and the transport method is made through UDP packets to the default TUIO port number 3333. Furthermore, jsprit [13], 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 [7]. CCV was selected compared to reacTIVision and Touchlib, because CCV has more filter options. The recognition of the camera from CCV requires the installation of the device driver named CL-EYE Platform Driver. Moreover, open source Unfolding library [29] 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 VRP is a well-known combinatorial optimization problem with many practical applications. Collaborative DSS using tabletop displays have not yet been used for this problem. In this paper, we present 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. The locations of the customers to serve are added using interactive Google Maps. The DSS extracts the geographical information of the selected locations, find the distances between them and solves the problem according to the specified model parameters of each decision maker. The solution of the problem is presented both on an interactive Google Map and on a pdf file. Decision makers can compare their solutions, collaborate to improve one solution by adjusting problem's parameters and find the best possible one.

In future work, we plan to include other VRP variants in order to enhance the DSS with other options. Furthermore, we plan to make a study in order to examine the collaboration aspects of the proposed DSS and enhanced them if possible.

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