Heuristics and Support for the Solution of Street Routing Problem

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Abstract. Servicing a large number of customers in a city zone is often a considerable part of many logistics chains. The capacity of one delivery vehicle is limited, but, at the same time, it usually serves a large number of customers. This problem is often called a Street Routing Problem (SRP). Key differences between Vehicle Routing Problem (VRP) and SRP are presented here. As presented, only using systems such as Geographical Information Systems (GIS) it is possible to effectively manage SRP. Besides classical measurements used in VRP, other, mostly qualitative, measurements are presented. All of these are named as visual attractiveness. Several new heuristics for solving SRP are evaluated on the real data and then compared. One of the key properties of GIS for use with the routing software is its flexible interactive and user-friendly environment. Paper presents a practical use of new heuristics with the ArcView and solution of address mail for several cities in Slovakia served by Slovak Post Ltd. Other Decision Support Systems that solve SRP are presented as TRANSCAD developed by Caliper Corporation or GeoRoute developed by Canadian Post and GIRO. in: Sheibani K (ed). Proceedings of the 1st International Conference on Applied Operational Research – ICAOR (2008), pp 32–44. Lecture Notes in Management Science Vol. 1. ISSN 2008-0050.

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1 Introduction

The Street Routing Problem (SRP), as a problem of servicing a large number of customers in a city zone, is often a part of many logistics chains. In the SRP category, we can include problems like meter reading, newspaper delivery, postal service delivery, waste removal, healthcare services.

Practical experience from the solutions of SRP in the Slovak Republic suggests that they are, in most cases, solved by an expert’s experienced judgment. The
main problem of SRP is that the number of customers is large and the number of delivery path combinations is enormous.

The SRP is in many cases similar to the classical Vehicle Routing Problem (VRP). There are some important differences between SRP and VRP.

- The number of customers in the SRP is large compared to the VRP. In the VRP the number of customers is in the hundreds, and in the SRP, it could be hundreds of thousand.
- The service time for one customer in the SRP is short and the route path for one vehicle contains several hundreds of these customers.
- The density of the street network in the SRP is high compared to the regular road network in the VRP.
- The distance between two close customers in the SRP is small and it is possible to get from one customer to another customer through a small number of possible network connections.
- Traffic regulations in the city zone are more complicated and more restrictive than traffic regulations in a regular road network. These regulations could greatly affect the expense for the routes.
- The access points to the customers are important and have a large effect on the total cost.

2 Experimental sample

SRP is a less explored group of problems than VRP and there is not a good, publicly available sample of data for method comparison. Authors, for example [6], are usually solving specific problems and it is difficult to compare solutions across these problems because each of them are somewhat unique.

It is necessary to use our own experimental sample, one that covers most of the typical SRP and, at the same time, it is possible to compare each of the solution methods. Our experimental sample was from several cities and large villages in the Slovak Republic. Customers were houses in these cities and full street infrastructure is available.

Data were collected manually from source maps ZM 1:10000, purchased from Geodetic and Cartographic Institute of Slovak Republic. The total number of customers in the sample is 101,977 and total number of settlements is 90, averaging 1,133 customers per settlement, which is more than the average number of houses in the cities and villages in the whole Slovak Republic. These data are not public at the moment.

3 Mathematical model of SRP

Mathematical model of SRP can be similar to the mathematical model of Capacitated Vehicle Routing Problem (CVRP) as described by Janacek [1].
\[
\min \sum_{r \in R} \sum_{i \in J', j \neq i} c_{ij} x_{ijr} \\
\text{s.t.} \\
\sum_{r \in R} \sum_{i \in J', i \neq j} x_{ijr} = 1, \ j \in J \\
\sum_{i \in J', i \neq j} x_{ijr} = 1, \ j \in J', r \in R \\
\sum_{j \in J} \sum_{i \in J', i \neq j} x_{ijr} \leq K_r, \ r \in R \\
\sum_{i \in J', j \in J', j \neq i} x_{ijr} (t_{ij} + \tau_j) \leq T_r, \ r \in R \\
\sum_{j \in S} \sum_{i \in S, i \neq j} x_{ijr} \leq S | -1, \ r \in R, S \subseteq J, | S | \geq 2 \\
x_{ijr} \in \{0,1\} \ r \in R, i \in J', j \in J', i \neq j
\]

Here \( J \) is a set of all customers, \( J' = J \cup \{S\} \) is a set of all customers and a depot, \( R \) is a set of all available vehicles and each vehicle can be used only once. \( c_{ij} \) is the travel cost from customer \( i \) to customer \( j \), \( b_j \) is the demand of the customer \( j \) and \( K_r \) is the capacity of vehicle \( r \). \( t_{ij} \) is the time required to travel from customer \( i \) to customer \( j \), \( \tau_j \) is service time of customer \( j \) where \( \tau_S = 0 \) and \( T_r \) is the daily time capacity of vehicle \( r \). \( x_{ijr} \) is a decision variable that takes value 1 if the link from \( i \) to \( j \) is used by vehicle \( r \) and customer \( j \) is served by this vehicle, 0 otherwise.

Equation (1) is the objective function, which minimizes the total travel costs, (2) ensures that all customers are visited exactly once, and (3) ensures that all customers are entered the same number of times as they are left. Equation (4) ensures that total demand of all customers that are served by one vehicle does not exceed vehicle capacity, (5) ensures that total traveling time for each vehicle does not exceed time limits. Equation (6) ensures that sub-tours not involving depot are avoided and (7) gives the domain for the decision variables. Presented model of SRP is similar to CVRP except the equations (5).
4 Visual attractiveness of routes

The visual attractiveness of routes is of great importance in practical routing applications and plays a central role in whether or not routes are adopted. As an example, in many business and other enterprises, service personnel (drivers) must serve geographically dispersed customers. The service region is divided into districts and each driver is responsible for their own district. These districts typically do not overlap. As such, drivers and their managers often notice that trips developed by algorithms to solve SRP may cross one another and are consequently reluctant to employ the resulting trips. The drivers believe that the trips must be inefficient if they cross. Since existing techniques do not explicitly consider solution shape, resulting trips are difficult to implement in practice.

Poot et al. [5] describe some possible parameters that could be used for measurement. The properties of compactness, crossing, and distance from cluster median are parameters that are hard to measure and are as important as other operational constraints. Therefore, they are often treated as soft constraints. There is no publication that describes these measurements in the detail. We have defined these measurements based on some experiments [3] as follows.

A route is considered to be compact if all customers in the route are within short distances of one another. One can measure compactness of route $i$:

$$\text{COMP}_i = \frac{\text{AvgDist}_i}{\text{AvgMaxDist}_i}$$

where $\text{AvgDist}_i$ is an average distance of two immediate following customers in the route $i$. For $\text{AvgMaxDist}_i$ we order distances between two immediate customers in route $i$ in highest order then we take 20% of longest distances and form these we create an average value. It is easy to see that in all cases $\text{AvgMaxDist}_i \geq \text{AvgDist}_i$.

As was mentioned in previous text operators are reluctant to employ resulting routes if routes cross one another. We use number of crosses as one of the measures for the visual attractiveness.

The measure $DGRB_i$ gives the average number of customers in a route that are closer to the center of gravity of another route than to the center of gravity of the route itself. Here, the center of gravity of a route is the center of gravity calculated from the coordinates of the locations of the customers in the route. We can measure it as:

$$DGRB_i = 2 \times \left(1 - \frac{|\hat{O}_i|}{|O_i|}\right) - 1$$

where $|\hat{O}_i|$ is a number of customers that are closer to the center of gravity of another trip, and $|O_i|$ is a number of all customers in the route $i$. Good solutions give this number equal to $1$. Poor solution can give us number -1. For practical use we limit the resulting values to the interval $<0,1>$. 

We can measure visual attractiveness as:

\[
VA_i = \frac{1}{\left(\frac{NC_i}{5} + \frac{1}{DGRB_i} + \frac{1}{COMP_i} - 1\right)}
\]  

(10)

where \( NC_i \) represents the number of crossings of route \( i \) with other routes in the service part of the route. We do not count crossings that are between the depot and first customers of the route and the last customers on the route and the depot. The reason for equation (10) is that we want to get visual attractiveness as a number in the range <0,1>. Values of visual attractiveness that are higher are usually more acceptable. We have to remember that in real life, customers are distributed randomly and street networks do not have compact density. In most of the real cases, we cannot get visual attractiveness measurement higher than 0.6. Our definition of visual attractiveness is one of the many possible and also there exists many other measurements that someone can create to measure the value of visual attractiveness.

Fig. 1. Solutions of SRP for the city of Malacky with the total length of 75,146 m and visual attractiveness of 0.375
5 New heuristics for solution of SRP

There is no heuristics that specializes in the SRP and also use criteria other quantitative measurements. We have tried to implement and compare nine new heuristics [4].

These heuristics are:

- Heuristics that use primary aggregation. These heuristics use cluster-first, route-second methodology. The goal is to create “natural clusters” and then run several traveling salesman problems - one on each cluster.
  - **Greedy algorithm – Unified Cluster First Route Second (UCFRS)** first estimates the number of clusters using some other usually simple heuristics (for example, Yellow [7]). Then this heuristics place centers of clusters solving p-median problem [8]. Then for each customer creates score value:
    \[ v_i = \min_{j} d_{ij} - \min_{k} d_{ik} \]  
    \[ (11) \]
    where \( \min_{j} d_{ij} \) is the road distance from customer \( i \) to the closest center and \( \min_{k} d_{ik} \) is the road distance to second closest center. First, take the customer \( i \) with the maximum value of \( v_i \), then customer with the second score etc. For each evaluated customer it is trying to assign it to nearest cluster based on their road distance to the centers if cluster limits (time, weight, number of customers etc.) allows it, otherwise it is assigned to second or third cluster.
  - **Revised greedy algorithm (UCFRS2)** is similar to the previous heuristic. The difference is that customers are assigned to p-centers based on the road distance, regardless of cluster limits. If some clusters are over the limits, then they are balanced. It uses a special transportation method algorithm for balancing.

- Shaping heuristics
  - **Two Steps Savings Heuristics (TSSH)** in the first step creates clusters using UCFRS2 heuristic. These clusters are not final, they are used only for an evaluation of savings if connecting two routes. In the second step, similar to Yellow modification of saving heuristics [7] are savings calculated as:
    \[ v_{ij} = c_{Si} + c_{SJ} - (\gamma + \lambda z(i,j))c_{ij} \]  
    \[ (12) \]
    where \( \gamma \) is shaping parameter like in the Yellow heuristic, \( \lambda \) is a new shaping parameter and \( z(i,j) \) is a function returning 0 if customers \( i \) and \( j \) belongs to the same cluster and 1 otherwise, \( c_{ij}, c_{Si}, c_{SJ} \) are road distance between customers \( i \) and \( j \) or depot and customer \( i \). Following steps are the same as in the classical saving heuristic. Simple routes starting from depot visiting one customer and returning to depot are generated, then \( v_{ij} \) are evaluated in the
order of values from the highest. If routes where are customers $i$ and $j$ can be connected (using all limits for routes), then these routes are merged.

- **Revised Two Steps Savings Heuristics (RTSSH)** uses the same logic as TSSH but savings calculated as

\[
\begin{align*}
  v_{ij} &= c_{Si} + c_{Sj} - (\gamma + \lambda_0) c_{ij}; & i \in I; j \in I & \text{or} \\
  v_{ij} &= c_{Si} + c_{Sj} - (\gamma + \lambda_1) c_{ij}; & i \in I; j \notin I
\end{align*}
\]

(13)

where $\lambda_0$, $\lambda_1$ are new shaping parameters. Heuristics is the savings heuristics actual saving parameter for connecting of routes where are customers $i$ and $j$ depends on the fact if these two customers were in the first step put in one cluster or not. If they are in the same cluster then saving is function of parameter $\lambda_0$; otherwise it is a function of parameter $\lambda_1$. The logic of heuristic is the same as previous one.

- **Metaheuristics**
  - **Tabu search for SRP (TABU)** starts with a solution created by RTSSH. It takes one customer from one route and it tries to attach him to the other route without reordering customers in either route. It also takes solutions that are worse than the existing best solution or solution that exceeds capacity limits in order to go out of the local minimum. It is modification of TABU search for VRP [9].

- **Heuristics using visual attractiveness**
  - **Revised Yellow heuristics (RYellow)**. It is saving method. It uses savings based on calculations of partial visual attractiveness when two routes are merged to one route:

\[
v_{jp} = c_{Sp} + c_{pj} - (\gamma + \mu(1 - ZVA_{jp})) c_{jp}
\]

(14)

where $\mu$ is new shaping parameter, $ZVA_{jp} \in [0,1]$ represents change in the visual attractiveness if the routes where customers $j$ and $p$ are located are merged to one route. Visual attractiveness calculated in this method uses only compactness and DGRB.

- **Two Steps Savings Heuristics with Visual Attractiveness (TSSH-VA)** works the same way as TSSH only after generating each solution it tries to find minimum of function in (15) instead of simple minimum cost or minimum length.

\[
\min UFV = w \ast VA + (1 - w) \ast \frac{UF}{UF_{yellow}}
\]

(15)

where $w$ is weight of visual attractiveness, $UF$ is a value of objective function (total cost, total length...), and $UF_{yellow}$ is a value of objective function for solution given by Yellow heuristic.
• Heuristics with fuzzy clustering
  o **Fuzzy Cluster Heuristics (FCH)** is a complicated heuristic. It uses clustering by "fuzzy c-means" (FCM). The membership of customers to each cluster is set as a triangle fuzzy number. It is similar to TSSH heuristic.

• Heuristics with mixed model of node and arc service
  o **TSSH that use NEARP representation of graph** is revised TSSH. In this variation of TSSH, the NEARP representation of graph [2] is used. Here some customers on the street segments are aggregated and street segment is viewed as a customer. We get a mixture graph where some customers are nodes and some customers are arcs.

We evaluated performance of each heuristics on the experimental sample data and table 1 summarizes the results of the experiments. The experiments were done on the 400 instances. These were original instances from experimental sample and variation of these instances using customer aggregation. Average number of customers in this experimental sample was 1038. On each case each heuristic was run one time.

<table>
<thead>
<tr>
<th>Heuristics</th>
<th>ALY</th>
<th>VA</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweep</td>
<td>75</td>
<td>0.29</td>
<td>7.5</td>
</tr>
<tr>
<td>Yellow</td>
<td>0</td>
<td>0.35</td>
<td>125.7</td>
</tr>
<tr>
<td>UCFRS</td>
<td>16</td>
<td>0.28</td>
<td>11.5</td>
</tr>
<tr>
<td>UCFRS2</td>
<td>10</td>
<td>0.40</td>
<td>21.3</td>
</tr>
<tr>
<td>TSSH</td>
<td>-3</td>
<td>0.38</td>
<td>228.5</td>
</tr>
<tr>
<td>RTSSH</td>
<td>-3.6</td>
<td>0.38</td>
<td>453.2</td>
</tr>
<tr>
<td>TABU</td>
<td>-4.0</td>
<td>0.39</td>
<td>12652.3</td>
</tr>
<tr>
<td>RYellow</td>
<td>-1.5</td>
<td>0.42</td>
<td>10468.2</td>
</tr>
<tr>
<td>TSSH-VA</td>
<td>-2.2</td>
<td>0.44</td>
<td>447.3</td>
</tr>
<tr>
<td>FCH</td>
<td>-1.4</td>
<td>0.39</td>
<td>212.1</td>
</tr>
<tr>
<td>TSSH-NEARP</td>
<td>-0.4</td>
<td>0.34</td>
<td>12.4</td>
</tr>
</tbody>
</table>

*ALY – average relative total length compared to solution by Yellow heuristics in %, VA – average visual attractiveness, TIME – average computing time in seconds*
In Table 1 the ALY parameter is calculated as

$$\frac{\sum_{s \in ES} UF_s - UF_{Yellow}^{s}}{|ES|} \times 100$$

where $ES$ is experimental sample, $UF_s$ is value of objective function for one set of data from experimental sample, $UF_{Yellow}^{s}$ is value of objective function for the same data set using the Yellow modification of savings method. For the comparison results of simple clustering sweep heuristics were presented. The Sweep algorithm used is proposed by Wren and Holliday in 1971 [10].

Each of proposed heuristics has some good qualities but also some weakness. Good heuristics are able to maintain good value of visual attractiveness (more then 0.35) and still provide good results in classical measurements as total length or objective function. For the practical use we would not recommend to use meta-heuristics because they are too slow for large volume of customers.

Fig. 2. Average value of cots and visual attractiveness of routes with parameters $\gamma \in (0, 9, 1.4)$ and $\lambda \in (-3, 6)$ for the TSSH
We did not create one superior heuristic that could be used for all SRP cases. We offer, in the decision support system for the SRP, a choice where the user specifies available time for a calculation and desired parameters of results and the system choose best heuristic(s).

6 Use of GIS for the SRP

Recent development in the real street routing problems shows that there is a need to make routing software a part of a larger system. One of the possible solutions to this is to integrate routing software within GIS. GIS can be helpful in the collection, storing and management of large geographical databases used in the routing software - i.e. transportation network databases and databases of customers. GIS can be also used for creation of all outputs from the routing software, including detailed maps for each route with the route description. One of the key properties of GIS for use with the routing software is the interactive and user-friendly environment. This is valuable for many real SRP, because as we have found out, there is always a need to work in a co-operation of expert-routing software. Routing software can find a good solution and explore the possibilities and an expert can change calculated routes to explore other possibilities based on the expert’s judgment.

GIS have several useful features that could help improve routing software performance. To mention only a few here - we may pay attention to the capabilities as safe database management, flexible symbols, map management, drawing capabilities, safety and interoperability.

Decisions support systems (DSS) are important for solving real SRPs. One use of the routing software results in not only a solution of the problem, but also the ability to explore several other possibilities, or perform operations like exchanging parts of two routes or seeing how changes in the transportation network, regulations or policies could affect the routes, expenses and other parameters. Currently there exist two trends in the development of DSS for SRP.

- Independent software packages specialized for SRP with limited amount of DSS capabilities. Here we can note software like GeoRoute from the Canadian software firm GIRO. It is not an open system. It is an expensive product that costs 1,000,000 EUR for one installation. As an example of other such systems, we can use TRANSCAD created in the US, which has some similarities to GeoRoute. GeoRoute is more feasible for solving the SRP because it is specialized for the street routing. TRANSCAD is more specialized in the node routing.

- Integrated systems based on the GIS or CAD. As an example, we can put ArcView with its ArcGIS Network Analyst. It is specialized in the node routing. The user can implement extension and then make it an integral part of the whole system.

An important feature of a decision support system is good visualization and a good editor. Tools that are able to visualize results are easily acceptable to users. Visualization also allows users to see any problems or discrepancies which are not
easy to find or implement by heuristics. The user can change starting conditions in
the problem to avoid these discrepancies, test the new model, and by several itera-
tions, get an acceptable result.

To shorten development time, we have chosen a standard GIS environment as
the base system for the data management. Fig. 3 shows the connections of all
components in the decision support system for solving SRP.

The integrator represents the main user interface. It controls each heuristic - the
connection of GIS database to heuristics or to an interpreter. It is used for model
creation and management. We used ArcView by ESRI as the main GIS tool, be-
cause it is an open system and it allows the user to program its functionalities. GIS
is managed from the integrator by the Avenue scripting language, C#, and VBasic,
depending on the version of ArcView. GIS is used in the system as a data man-
agement tool, editor, for visualization of results, and for editing these results.

The module for heuristics also includes a system for SRP model management
and algorithms for evaluation of quantitative and qualitative parameters of solutions.

The interpreter is a supplemental module, which helps one to visualize other
parameters of SRP that are hard to visualize in GIS environment.

For simplicity, we expect that the GIS database for each SRP case will have a
unified form. Data are stored in the natural GIS database - in this case it is an
ESRI shapefile format and relational database.

Fig. 3. Decision Support System using of GIS for SRP
7 Conclusions

There are expanding activities in the cities that can be presented as street-based tasks. We introduced some methodology for solving general SRP.

Criteria other than the usual measurements are needed to evaluate the results. In particular, visual attractiveness needs to be added as a non-standard quality measurement for resulting routes. There is some relation between visual attractiveness and quality of resulting routes.

This paper presents 9 new heuristics for the SRP and their promising results. Our analysis indicates that there is not single heuristic that could solve any SRP case. Instead, a combination of heuristics is needed to solve a specific case.

DSS for SRP can address this shortfall. We presented DSS based on the GIS database. We used DSS for 5 cities in Slovakia and after applying the solutions we were able to shorten total length of all tours up to 10% in each case.

<table>
<thead>
<tr>
<th>Route</th>
<th>Length [m]</th>
<th>Total time [min]</th>
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<tbody>
<tr>
<td>I</td>
<td>8367</td>
<td>277</td>
</tr>
<tr>
<td>II</td>
<td>9881</td>
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<td>VI</td>
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<td><strong>TOTAL</strong></td>
<td><strong>102477</strong></td>
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Table 3. Routes of postmen in city Galanta calculated using TSSH.

<table>
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<tr>
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References