Using variable neighborhood search to locate fire and rescue resources for Räddningstjänsten Östra Götaland

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I. INTRODUCTION

January 1, 2010, the fire and rescue services in the two Swedish municipalities Linköping and Norrköping joined forces and formed “Räddningstjänsten Östra Götaland”. One of the reasons for the merging was to find ways of more efficient utilization of the existing resources. For example, a location of a fire station that might have been effective before the merge may not be optimal for the new larger area. This gave rise to the question of how the resources for the entire county of Östergötland (which consists of 13 municipalities) should be located, if all municipalities in the county collaborated like Linköping and Norrköping.

Thus, in this work, we give suggestions on how the fire and rescue resources in the county of Östergötland could be located in order to minimize the response time to housing fires and traffic accidents, which are the two events to which the fire and rescue services respond that causes the largest amount of serious injuries and loss of life [1].

II. LOCATION MODELING

An optimization model is constructed to suggest locations for three different types of response units; base units carrying four to five fire fighters, ladder units with one fire fighter and small units manned by one to three fire fighters. To provide a “full response” for any accident, at least one base unit and five fire fighters are required. If the event is a fire in an area with high-rise buildings, a ladder unit and one additional fire fighter are also needed. The small units can provide a “first response” to any accident, and can be used to obtain the necessary five (or six) fire fighters if the first base unit on site lacks the man power. The ladder units can only be used for fires in high rise building, and cannot be used for first response or other types of accidents. Each unit also has a specific call out time, varying between 90 – 360 seconds.

The objective function of the model is the sum of a weighted combination of the time to the first response (when the first unit has reached the accident site) and the time to a full response (for traffic accidents, when at least one base unit and five fire fighters have reached the site) multiplied by the expected number of accidents:

$$\text{Min} \sum_{o \in O} \sum_{i \in I} D_{oi}(\alpha f_{oi} + \beta t_{oi})$$  \hspace{1cm} (1)

where $D_{oi}$ is the expected number of accidents of type $o$ in demand zone $i$; $f_{oi}$ is the first response time for accident $o$ in zone $i$ and $t_{oi}$ is the time for a full response. $\alpha$ and $\beta$ are weight parameters that can be varied by the user to obtain solutions with different characteristics. The model can be easily reduced to a $p$-median problem, which is known to be NP-hard.

III. SOLUTION METHOD

Solutions to the mathematical model are obtained using a reduced variable neighborhood search heuristic, which has proved to be efficient for large $p$-median problems [2].

Three different types of moves – “interchange”, “local interchange” and “swap” - are used, resulting in nine different neighborhoods. In the interchange move, one, two or three units are moved to new locations. In local interchange, a unit may only be moved to a new location close to the current one. In the swap move, the locations of one, two or three pairs of units are swapped. It may be noted that the swap move is beneficial since the units are heterogeneous.

During the solution process, a new candidate solution is randomly generated from one of the neighborhoods. If the new solution, $x'$, is better than the currently best found solution, $x$, the search moves to this solution ($x := x'$). The same neighbourhood structure is then used to generate a new candidate solution originating from the new best found solution, $x$. If $x'$ is worse than $x$, the algorithm iterates to one of the other neighborhoods. The search continues for a pre-specified number of iterations.
IV. COMPUTATIONAL RESULTS

Necessary input data, apart from the conditions described previously, consists of forecasts of the accidents modelled and expected travel times for the units. The forecasts are based on regression analysis type models provided by Karlstad University (for fires) and the Swedish National Road and Transport Research Institute (VTI, for traffic accidents). These forecasts are delivered for 250m-squares, of which there exist too many in the county to be computationally tractable. Therefore, the data is aggregated to 3000 demand points using a k-means procedure [3]. Travel time data from each demand point to every other demand point is provided by the Swedish agency for growth policy analysis. The algorithm is run for one million iterations on a HP ProLiant DL385, which takes about three hours.

Results are produced for a number of different scenarios, where parameters, input data and in some cases model characteristics are varied. In Table 1, a selection of the results is presented. Sol is the solution id while α and β are the weight parameters used in the solution (these will affect the objective function value). Obf the objective function value of the solution; f10 is the percentage of the accidents that are covered within 10 minutes with a first response; t10 is the percentage of the accidents that are covered within 10 minutes with a full response; f15 and t15 are like above but for a coverage time of 15 minutes; fmean and tmean are the mean first and full response times in seconds respectively; finally Impr is the improvement (in percent) from the current solution.

<table>
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<tr>
<th>Sol</th>
<th>α</th>
<th>β</th>
<th>Obf</th>
<th>f10</th>
<th>t10</th>
<th>f15</th>
<th>t15</th>
<th>fmean</th>
<th>tmean</th>
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<td>92%</td>
<td>365</td>
<td>458</td>
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</table>

The results in Table 1 indicate that it is possible to improve the response times 20-25% from the current situation. It is evident that a focus on first response (sol 25) gives shorter first response times, when compared to focus on full response (sol 27) which gives shorter full response times. The parameter settings for α and β in sol 46 has been selected to give a good balance between first and full response, resulting in solutions that look attractive and reasonable from a user point of view. This setting also produces very competitive results when studying the mean response times. In sol 52, the algorithm is allowed to use the ladder units as resources for all accidents, just as the small units. This gives the model incentive to focus more on the first response component of the objective function, giving a high coverage for first response and the lowest mean first response time, while the full response time increases compared to the other solutions produced by the model. The reason for this is that model utilizes the ladder units as first response units, and to complement base units with less than five fire fighters, rather than placing them close to high-rise buildings. This may be due to the fact that the number of traffic accidents and other housing fires clearly outnumber the expected fires in high-rise buildings.

V. CONCLUSIONS

The results suggest that by optimizing the locations of fire and rescue resources in the county of Östergötland, the response times to housing fires and traffic accidents can be reduced with around 20%.

REFERENCES