German data sets for comparing ambulance location models

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Abstract

Ambulance planning includes the problems of locating ambulances and bases as well as relocating ambulances throughout the day. Especially for determining (optimal) ambulance locations many different models and approaches exist. Most of them are presented for a special country or region. It would be interesting to study how they perform for other regions, especially for Germany. For doing so, a set of instances is needed that includes different characteristics. We therefore discuss accessible data and present a set of instances derived for Germany.

Keywords: Health Services, Ambulance Planning, Data Sets

1. Introduction

For each Emergency Medical Service (EMS) system, the location of ambulances and bases is crucial for the main task of helping patients as soon as possible in case of an emergency. Operations Research can help finding good (optimal) locations with regard to an objective. Often, the (main) objective is to maximize the coverage. A demand location is usually called covered by a base location if it can be reached within a maximum time. Other objectives minimize the costs or maximize the survival probabilities.

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The first model to locate ambulance bases was introduced by Toregas et al. (1971). The Location Set Covering Model (LSCM) determine the minimum required number of bases as well as their locations to cover the entire region within a fixed time threshold. Church and ReVelle (1974) presented the Maximum Coverage Location Problem (MCLP) to maximize the coverage assuming a limited number of bases. Another important model is the Maximum Expected Coverage Location Problem (MEXCLP) by Daskin (1983) that explicitly takes the coverage depending on the expected busyness of every ambulance into account.

Relocation approaches are applied at the operational level of EMS planning. Gendreau et al. (2001) proposed one of the first real-time ambulance location models. Depending on the current state of the system good relocations are determined by solving a location approach that uses two coverage standards. Gendreau et al. (2006) published a similar approach that bases on the MEXCLP instead.

Many models assume an underlying graph with nodes representing demand and possible base locations. Edges are weighted by the driving times between the nodes. Other approaches assume a grid structure for the underlying city/region. It means that the city or region is divided into equally sized squares, e.g. of 1 km^2. Each square presents a demand location and a subset contains the potential base/ambulance locations. Often, Euclidean distances are used for these approaches and distances are measured between the centers of the squares. For example, Chanta et al. (2014) presented a bi-objective coverage location model that is solved for a data set with grid structure. Also, several relocation approaches base on a grid structure, as for example the multiperiod set covering location model for dynamic redeployment of ambulances by Rajagopalan et al. (2008).

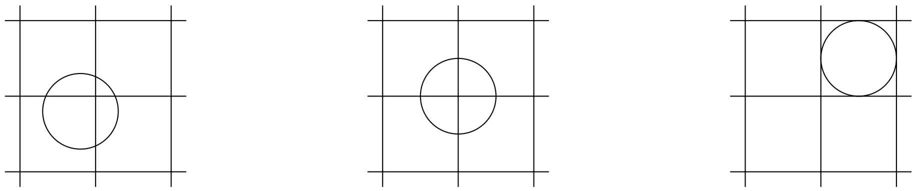
To the best of our knowledge, only Ingolfsson has published EMS data, in this case for the EMS system in Edmonton that he used for his research. It is one (large) instance consisting of 180 demand nodes and 16 base location. The data set includes the following information: (1) the average busy time for ambulances (in seconds), (2) the average number of calls for each demand node, for each station-demand node pair (3) the average response times (in seconds), (4) the standard deviation of response times (in seconds), (5) and the deterministic coverage for an 8-minute threshold (as 0 or 1), (6) the survival probability for deterministic response times, (7) the expected coverage for probabilistic response times for an 8-minute threshold, (8) the survival probability for probabilistic response times, and (9) the capacities for each station (as the maximum number of ambulances).

Often, models are fitted to the concrete problem they were developed for which means also for the considered EMS system (country). This also involves the underlying structure, i.e. network or grid. It is unclear if a model that performs well for a grid-based instance is also good for a network instance and vice versa.

To study this instances must be available in both structures. To the best of our knowledge, these "double-structure instances" have not been presented so far.

One problem is that if the grid structure is not given, but must be defined first, this can be very challenging. This is especially true fur rural areas with small villages while for a city the grid structure seems more suitable. Figure 1 shows three possible arrangements of a demand location (e.g. a village) in a grid. Cases a) and b) show what often happened when we tried to put a grid over a rural area and case c) represents the ideal situation that we would want. In case a) the center of the square is near the center of the demand location, but small parts of demand location are situated in the adjacent squares. This means the distance calculation is acceptable but the demand is not well represented in the grid. In case b) the demand location is distributed on several squares evenly, but the center of the squares are not representing the actual position of the demand location. This not satisfactory for the distance calculation. In case c) the demand location is perfectly centered in only one of the squares, therefore we get an optimal representation of the demand location with the center of the demand location being used for the distance calculations. Note that also the size of the squares could vary. Often, 1 km^2 is chosen as this makes computations easy. But in some cases, this might be too small (e.g. for very large regions this would lead to too many squares) whilst in others it might be to large (e.g. when cities have a very fine structure or when rural areas consist of only very small villages).

One last aspect that we want to take into account for building the instances is that different internal city structures exist. Figure 2 presents three types of internal city structures. The concentric zone model is basically a generalization for cities. It was the first model to be published by Burgess (1967). Chicago is a well-known example. The sector model was published by Hoyt



(a) (b) (c)

Figure 1: Grid structures

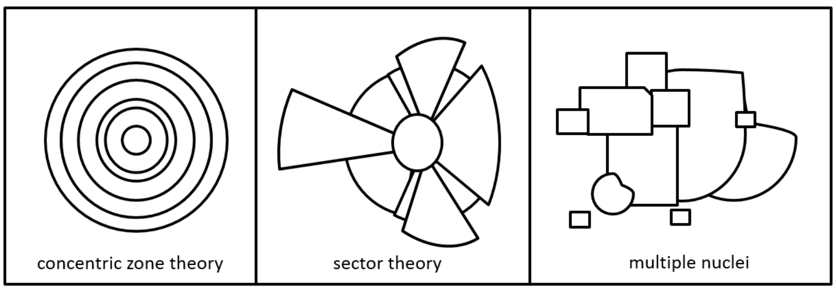


Figure 2: Generalization of internal structure of cities [Harris and Ullman (1945)]

(1939). With this model the arrangement of the sectors varies from city to city. The multiple nuclei model by Harris and Ullman (1945) represents many cities quite nicely. Figure 2 shows only one possible pattern among innumerable variations.

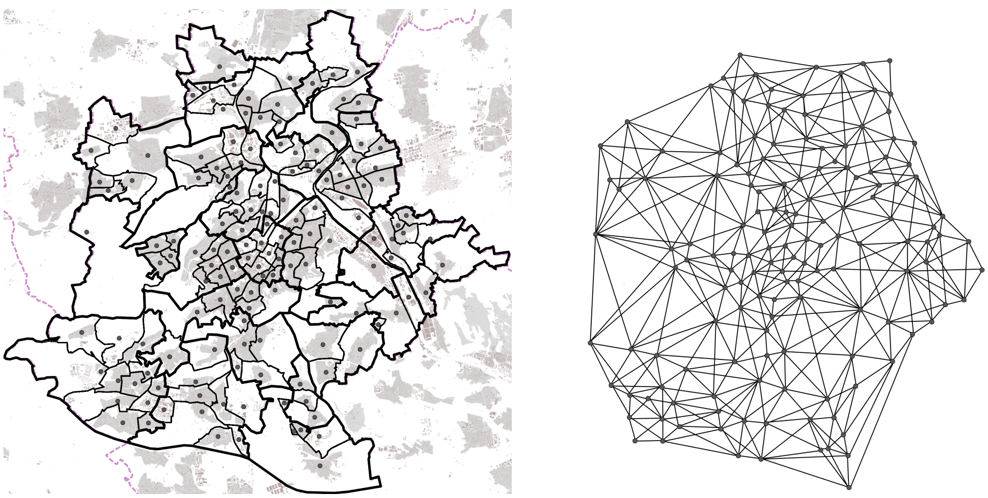
Examples for the three models in Germany are (1) Düsseldorf, (2) Hamburg and (3) Berlin.

2. German EMS Instances

The data set we developed contains instances with the network and the grid structure for cities as well as rural ares. The demand for the nodes/ squares is first expressed as the number of inhabitants. For the network structure, the inhabitants per district were used. For the grid structure, the inhabitants had to be divided between the squares first. We assume a linear relation between the number of inhabitants and the expected demand and can therefore also assign single values for the demand.

We built instances with a grid structure for cities of Stuttgart, Karlsruhe, Freiburg, Düsseldorf, Hamburg and Berlin. Distances between squares were calculated with the l2-metric and each square was indicated by its center.

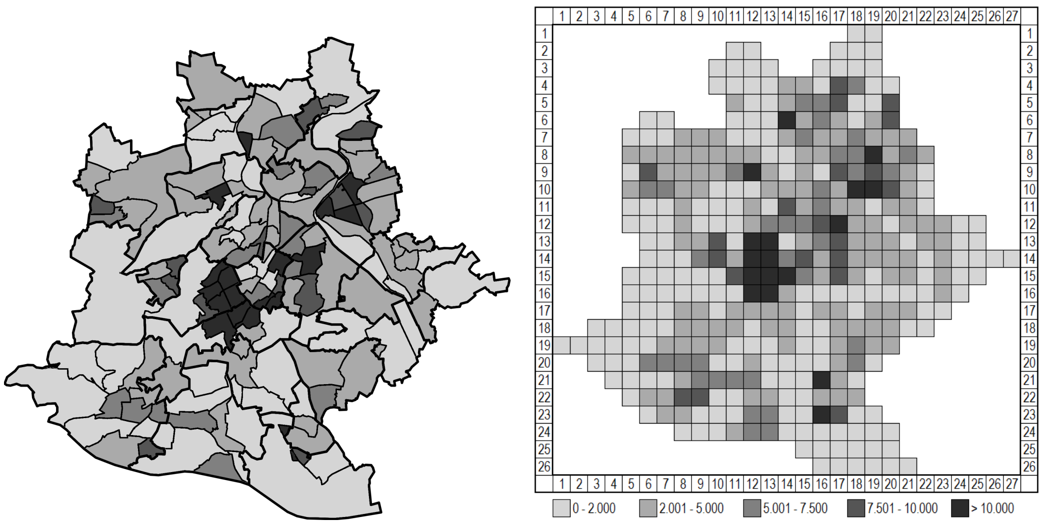
Instances with a network structure were developed for: the city of Stuttgart, the city and county of Karlsruhe, the city of Freiburg and the county of Breisgau-Hochschwarzwald, the cities of Heidelberg, Mannheim and the county of Rhein-Neckar and the county of Schwarzwald-Baar as representative of a rural region. For these instances the position of buildings and residential areas indicated by OpenStreetMap were utilized to pinpoint a suitable location of the demand node in the network. We needed exact coordinates for the representatives of the districts/nodes to calculate distances using the Google Distance Matrix API.



(a) Map and districts (b) Network structure

Figure 3: Stuttgart - network instance

Figures 3 and 4 show both structures for the city of Stuttgart. First, we have the city map showing the 148 districts and the chosen representation points. These points then form the network. Note that for determining the arcs several possibilities exist: (1) all nodes are connected which makes the network often quite large, (2) only those nodes are connected that can directly be reached from one another or (3) an edge is only drawn if a node can be reached from the other within the given response time. Figure 3 b) shows only a subset of the 3225 edges for case (3) (when assuming a maximum driving time of 15 minutes) to make the general structure of the network



(a) Population density (b) Grid structure

Figure 4: Stuttgart - grid-based instance

visible. For the grid structure we first coloured the districts depending on the population density and then fixed the grid structure. The demand was then set according to the population density in each square.

Other parameters that describe the instances include: (1) the possible locations for bases; either all demand locations are feasible, e.g. for a completely new analysis of the considered region or only a subset of nodes/squares is available. As far as we got the information we incorporated already built bases and reasonable new locations, e.g. large parking lots or empty spaces. (2) The number of emergency medical vehicles, in total and for each possible base location separately. (3) The time threshold(s) for the response time. (4) Further parameters that are only needed for a subset of models as busy fraction(s), service level(s) and reliability factors.

3. Conclusion and Outlook

In this paper we have explained the need for data sets in order to compare approaches for ambulance planning. We have discussed accessible data and presented a set of instances for several German cities and regions. They cover both the network and the grid structure. As some instances are developed for both structures, it is possible to compare approaches that use either one of the structures.

An obvious next step is now to use the instances to test and compare different approaches for the location and relocation of ambulances. Additionally, we want to send the instances to the coordination centers in charge to hopefully get some feedback on how good we modeled practice with our instances.

It would be nice to also include the information on emergency doctors (their locations and numbers) and build models and/or simulations that explicitly take both, ambulances and emergency doctors, into account.

Once we successfully used the instances to compare approaches and studied their applicability for Germany, we plan to make the instances accessible.

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