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A study of Locations for Mobile Hospitals in Dalarna

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Abstract:

Due to growing population over the past decades, settlements are scattered in sparse as well as dense clusters across Dalarna County. However, irrespective of any physical, social or economic conditions, free public health care must be available at a minimum and equal distance of travel for all citizens of a region. In the current scenario in Dalarna, around 16% of the population travels beyond 10 km to reach their nearest medical facility. The aim of this study is to suggest the most favorable locations for Mobile Hospital services across Dalarna County, based on spatial analysis of accessibility, population coverage, and importantly, in a way that travel distance, is minimized and equal for all. This study makes use of Multi Criteria Analysis methods. The problem of mobile hospital site selection is broken down into criteria, and Analytic Hierarchical Process is used to evaluate weights for each criterion. Then, a weighted overlay results in regions with score-based suitability for a mobile hospital. Maximum population coverage based Location Allocation analysis results in generating a proposed Facility and Demand Coverage output. The results show an increase in coverage of population, while meeting the requirements of criteria in the aim.

Keywords: Mobile Hospital, Analytic Hierarchical Process, Weighted Overlay, Location Allocation, Travel Distance
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1. Introduction

Sweden is well known for its world class healthcare facilities. (Medical Express, 2018) The healthcare is decentralized, such that each region is responsible for primary, specialist and other types of health care of its residents. Seventy percent of healthcare services are funded through local government taxes (Internations, 2020). This means that every earning citizen contributes their share to the healthcare, which has eventually allowed free public healthcare for every individual registered in the Swedish National Registry (OECD, 2019).

As specified by Sweden’s health and medical services act, it is a requirement that health care must be delivered on equal terms for the whole population. Hence, ideally all residents are entitled to equal access of publicly funded health services (OECD, 2017). This should be applicable both, socially and geographically.

This brings us to the main direction of study in this thesis, which is, studying geographic locations for placing 15 healthcare facilities in form of mobile hospitals to regions uncovered, in Dalarna County. This problem should be solved in order to meet the requirement that equal geographic reach should be established for medical facilities, and travel times should be nearly equal to all.

A mobile hospital is a smaller version of a hospital, or a medical care center that is fully equipped with medical equipment necessary for emergency purposes. It can be moved swiftly to a new location and settled there in the scenario of high emergency (Bakowski, 2016). In the context of this study, our study area is Dalarna in Sweden, and 15 mobile hospitals are to be placed across multiple locations in Dalarna. The study is carried out to get specifically 15 resultant locations for mobile hospitals because 15 it is the required number of mobile hospital units quoted by Region Dalarna for this study, based on their funding limitations.

Current Scenario

Dalarna County in Sweden is the study area for this thesis. It is located in the Mid-West part of the country and consists of 15 Kommuns (municipalities), which are further divided into minor semi-municipalities, and covers a total area of approximately 30,000 sq.km. Each municipality is responsible to the health care of its residents.
Vårdcentral (Health care facilities) are provided in every municipality, while there are 4 main hospitals in Falun, Avesta, Mora and Ludvika for more serious conditions. Region Dalarna is the government organization responsible for healthcare for Dalarna County (Region Dalarna, 2020).

Borlänge, one of the largest cities in Dalarna has a radial distance of an average 5 km from the city center to the outer banks of dense settlement. Hence, it is assumed here that residents of all other regions can travel at least this much (5km) distance to reach a medical facility. Considering other cities in the county are not equally dense, and far more spread with respect to settlement pockets, the assumed travel time has been increased to 10 km as a consideration to wider settlement spread across the entire county.

Given below is Figure 1 that displays the population points (Populations points are latitude-longitude based location points across Dalarna County at which number of population were recorded. Each point has a corresponding value which stores the magnitude of population recorded at that location) in the county, in contrast with the Service Area (spatial coverage) of 10 km from each medical facility. It was observed that even though the number of population points covered is low, the total magnitude of population covered is still much higher. This means that even though the area covered by the service areas of 10 km is small, it still covers a large chunk of the total population of the entire county. This is because these already existing medical facilities are present in dense urban areas of major cities like Falun, Borlänge and others, which contain majority of the population of the county.
Fig 1: Population points in Dalarna 10 km covered by service area of medical facilities

It is observed from this initial part of the study, that around 240,116 out of an approximate total of 286,004 numbers of individuals are currently covered by medical facilities within 10 km distance. This is according to the 2017 population GIS dataset, which is the latest freely available spatial dataset. This means almost 84% of the population groups can travel a maximum distance of 10 km in order to reach their closest medical facility. However, 16% of the population still has to travel major distances that can range until 50 km.

Aim

The aim of this study is to use Multi Criteria Decision Making (MCDM) in order to suggest 15 locations for placing Mobile Hospitals across Dalarna County, such that they meet the following requirements:

1. The travel distance to these newly suggested facilities should not exceed 10 km for populations residing in the respective proximity.
2. The newly suggested facilities should account for coverage of maximum possible population
3. Accessibility of the newly suggested facilities through roads as well as public transport. The accessibility requirement also includes the newly suggested locations to be closer to fire stations
4. The analysis should be carried out for populations that are currently uncovered by existing medical facilities within a 10 km distance

Part of these requirements are broken down in the methodology as individual criteria (the remaining parts of the requirements are met using Location Allocation tool, explained further in this section), and Analytic Hierarchical Process (AHP) should be used to obtain weights for each criteria. Next, a weighted overlay using the AHP weights method, in combination with Location-Allocation analysis should allow to narrow down to 15 best ('best' with respect to every requirement of the study) latitude-longitude based locations for the newly suggested mobile hospital facilities.

2. Literature Review

Studies of location analysis for hospitals and other medical facilities are popular, and a plethora of literature is available. These studies consist of a range of methods, tools and approaches used for different scenarios across the globe. However, one of the common factors in most of these studies for allocating medical facilities is the consideration of travel distance between the proposed location of the facility and the population or residential area spread near it. Mobile hospitals are a relatively new concept, but their basic provisions are similar to the facilities provided by health care centers and clinics. Hence even though there was a limited literature for mobile hospital studies directly, the basic literature required for sections of this study are covered by studies that were meant for hospitals and medical care centers.

To begin with, the importance and impact of population distance to medical facilities is well discussed in (Kelly, Hulme, Farragher, & Clarke, 2016). The paper investigates the impact on health outcomes caused by differences in travel times to healthcare centers, by bringing together multiple studies that have calculated the accessibility of residents to medical facilities. A set of 108 studies were considered in the inclusion criteria, and their outcomes were reviewed. It was viewed that 77% of the studies identified a degrade in health outcomes in proportion to the
distance they had to travel for healthcare. This means that those patients that travelled more than others, experienced worse health indicators compared to those that lived close by.

In, (Gowrisankaran, Nevo, Robert, & Town, 2015) the author discusses how sensitive patients are to willingness to travel time. The willingness to travel decreases with increasing age. Further, looking from an economic perspective, a five-minute increase in travel time reduces hospital shares between 17 to 41%, which means that the investments made in these projects by stock buyers reduces. In another research paper, (Raval & Rosenbaum, 2018) studies the effect of travel time of hospitals on its demand and conclude that on an average, increase in distance causes a decrease in demand for a facility. A one-minute increase in the travel time can cause up to 9.7% decrease in demand for the same facility.

The analysis of the above-mentioned papers highlights the importance location plays while selecting a site for a medical facility. Given that the location is the main outcome of the study, spatial analysis is required to reach practical results. New technologies such as Geographic Information Systems (GIS) have the capability to analyze data using spatial factors. This means that even the location of an object, and its geographic neighbors plays a role in deciding its behavior. One of the most famous example is the popular study by Jon Snow in London, 1854, who identified the source of spread of Cholera outbreak in London as contaminated water pumps by mapping deaths from Cholera, and features present in the surrounding, using GIS. This was one of the first time that spatial analysis was used for solving a medical problem. This study allowed an informed decision to be made while deciding placement of medical facilities (Begum & Archivist, 2016).

Multiple studies have been carried out in the field of GIS in order to solve hospital and health care facility related issues. (Gesler & Perry, 2000) carried out a study in Andean Bolivia, where they used GIS to find the access of healthcare by residents in distant areas. (Hare & Barcus, 2001) made use of travel time, distance, and other geographical distributions by using a GIS framework in finding a correlation between heart related hospitals, and their accessibility. (Gordon & Womersley, 1997) have described the productivity of GIS and its superiority in making use of spatial analysis for public health planning.

In a recent study, (Zhou & Jie, 2012) have addressed the problem of increasing demand for health acre by the general public in Beijing, China. Use of GIS approach has been made to
counter the unbalanced medical resources spread geographically. The method used is to select a site for a new hospital using GIS based Multi criteria analysis. Weight setting for each factor in the suitability was done with the use of Analytical hierarchical Process and Rank Order Method. Sensitivity and Necessity checks were applied to each factor in the analysis. These check were applied to assess the sensitivity to weight change of the factors considered. The overall scores for very site were calculated after processing its individual score from every factor. This resulted in many candidate locations, and hence, allowed even further extra conditions to be applied on those candidates. This led to recognizing the most optimal sites that fulfilled the requirement criteria. The advantage of his method is that every site was evaluated and scored, and hence instead of binary outputs, a relative scale of suitability was generated. This allows to recognize the next best facility as well. This study, although dealing with healthcare for people, was done using resident map as an input, rather than population map. In the scenario a population map is used, precise results could be stipulated, because while population provides an accurate number of people living in an area, the resident map provides the number of houses. The variance in number of members per house is small, but yet significant when assessing large areas like a county. This is because the large areas are inclusive of people from all social backgrounds, which plays a role on family size.

In another recent study (Rahimi, Goli, & Rezaee, 2017) have carried out a location allocation study for a new hospital site in Shiraz, Iran, using Multi Criteria Decision making technique (MCDM), integrated with GIS. This allowed connecting non-spatial data to locations creating a spatial database. For this study, Multi Criteria Evaluation functions are combined into a GIS software, using the Spatial analytic hierarchy process technique. Spatial analytic hierarchy process (SAHP) is a spatial analysis technique that combines AHP, which is an MCDM technique, with spatial data in GIS environment. Literature review was used to identify the criteria that play a role in hospital site selection. Further, each of these factors was provided a weight based on AHP. The input to the AHP came from a questionnaire circulate to a mix of professionals working in the medical fields in Shiraz. All the factors were converted into continuous raster surfaces, instead of disjoint points, line and polygons. This assures the presence of value for every pixel of the study area. The results evaluated the current location of hospitals as well and marked them on a suitability score. This research provided a solution to
create weights for factors for the analysis. Finding factors and a method to weigh them was a barrier in this thesis. Using the method of creating questionnaire targeting experts from the field has helped in overcoming this barrier in this thesis.

3. Methodology

Overall Workflow
In brief, the criteria (/factors/layers) that play a role while assessing the suitability of a site for a mobile hospital facility are identified through literature reviews and by browsing through freely available datasets. They are then filtered and narrowed down to 5 criteria, based on availability of the data for Dalarna County, in GIS compatible format (Listed in Table 2). This GIS data was available in vector format, such as distributed and scattered points and lines, and had to be converted into continuous raster surfaces, such that instead of scattered points, continuous data surfaces across the entire county are available. The means that if population file was initially present in point wise vector format, there would be some areas in Dalarna County that would have points, and hence, would have associated values; and the rest empty spaces would be null values. To generate data across null values as well, the vector points are converted into a population density surface, which is a continuous raster surface with a value on every point across the County. Hence, now the regions that were null in the vector, have some ‘density’ value in raster form, even if it is 0. Data for all the criteria were cleaned, cropped, merged, filled and limited to the geographic boundary of Dalarna.

Next, a questionnaire was generated to pair wise compare importance level of each factor,. This was shared with professionals working in the medical and urban planning fields. The output of this was fed into an AHP, where overall weights for each factor were calculated, allowing the criteria to be assorted in order of importance. These weights would be used in weighted overlay. Here, since all the different factors had datasets downloaded in different formats and sources, there was no standardized number of classes within them. Attributes of each factor were hence reclassified to bring to a standard level of classes. Within each criteria, each class was ordered according to status of importance. This means that if initial population density surface had 20 classes for a range of 20 density values, these were then brought down to wider ranges of 5
classes, with high density classes having more importance than low density classes. This was repeated for every criteria, and all these criteria were then input into a weighted overlay, with the AHP output weights as the input weights here.

A group of sites with scores high to low were generated from the weighted overlay, and sites with best scores were extracted. These are the preferred sites for a new mobile hospital facility, but have to be further narrowed down to a finer latitude-longitude level to meet all the requirements of the aim. To do this, location allocation tool was used. The location allocation tool consists of demand points and facility points. From a wide range of facility points, it can identify top ‘n’ number of facility points that show the highest coverage of demand points. Sample facility points at 1 km interval were generated across sites having high scores, and each facility point was evaluated for the demand it covered. Population points currently uncovered by existing medical services were considered as the ‘demand points to be covered’. This allowed narrowing down to top best 15 points suitable for a mobile hospital. The above methodology is pictorially represented in Figure 2.

Fig 2: Methodology chart
Step 1: Delineating Factors for the study

For a multiple criteria analysis, the criteria need to be first delineated, and must have relevant reasoning to be considered in the study. Another reason that affected the selection of factors was the availability of data. Many literatures have reviewed factors, and some of the most common, and influential criteria can be summarized in the following Table 1.

Table 1: Factors/Criteria used for Weighted Overlay analysis

<table>
<thead>
<tr>
<th>Hospital Type and Scale</th>
<th>Criteria/ Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hospital</td>
<td>Population, rate of population, projected rate of population, travel time, proximity to major transit facilities, distance from other hospitals, land cost, socio demographic factors, contamination</td>
</tr>
<tr>
<td>Health Care centers</td>
<td>Population, distance from arterial streets, distance from other hospitals, contamination, distance to fire stations</td>
</tr>
</tbody>
</table>

The factors presented in the results section in Table 4 were then narrowed down on, based on availability of data/capability of producing data.

Step 2: Data Sources and Processing

The data for this thesis is open source, and from a combination of Swedish National websites. The data was mostly downloaded as GIS compatible shapefiles, but also, in other formats. However, to carry out a weighted overlay using GIS, all the data needs to be first, projected in a common projected coordinate system. This is done so that linear and aerial measurements can be made across the data, that match the actual surface of the earth. Next, every layer has to converted from a vector shapefile, into a continuous raster surface. Different methods of cleaning and preprocessing that data are used depending on the type of source raw data. However, the common steps include clipping portions of data lying outside the Dalarna County boundary, merging broken/multipart datasets.

Software’s and extensions used to process the data

1. ArcMap 10.5
   Extension: Spatial Analyst, Network Analyst
2. ArcScene 10.5
Following are the data sources for each data, and the processing done on them.

1. Population: The population data source was ordered using the open source Geodata Extraction tool. This data I present across the years 2013-2017, latest. Hence, the analysis was done using 2017 data. The rate of increase in population has not changed significantly in Dalarna, and hence, ratio wise, this analysis can still use this data. The population data was available on levels of 100 meter resolution, semi-municipality, municipality and county. For precision, the 100 meter resolution data was used. A centroid was generated for every 100x100 m cubes, and appended to the value of that cube. Hence, the resultant is 100 meter spaces point shapefile, with each point containing age wise and total population.

To convert this data to raster, a density map was calculated for this layer. Hence, a continuous raster was generated, where pixel value =0 for when there were no points over it, and pixel value= high for when there were numerous points over that pixel.

The Figure 3 shows the output population density map of total population. The green regions represent low density, while red show high density.
2. Bus Stops: For the bus stops, data was extracted from the Dalatraffik website, which is the official organization for public transport in Dalarna. The Dalatraffik website contains a map with bus stop location in the ‘book a ticket- choose location’ section. The source code of the web page calls a text file containing bus stop code, and latitude and longitude. This data was cleaned using Excel, to separate and format text to desired column formats. This was then transferred to ArcMap and projected into a coordinate system. To convert the data into raster, rings of Euclidean distances were calculated from each bus stop, until the boundary of Dalarna County. This is evident in Figure 4.

![Fig 4: Zoomed in view of bus stop with Euclidean distance buffer indicating increasing radial distance rings from bus stop](image)

3. Roads: Roads were ordered from the open source Geodata Extraction Tool, which is an open source GIS database portal. This road data was available in multiple layers, such as main roads, streets, highways. A combination of all these roads was created. This file was present for only half of the county and had to be merged with the other half. The mapping of the merged files was cross checked to ensure continuity in road lines. This file was converted to raster using rings of Euclidean distances from each road segment, until the boundary of Dalarna County. This raster is shown in Fig 5.
Fig 5: Zoomed in view of roads with Euclidean distance buffer indicating increasing radial distance rings from road

4. Existing Services: This data was extracted from the 1177. se websites ‘Find care center’ page. 1177 is the official Swedish Government healthcare website. This webpage consists a map that makes a call to text file with XY location, overlaid on Google maps base map. Hence, these locations were easily available by manipulating the source code of the web page. Euclidean distance was used to create raster rings, as shown in Fig 6.

5. Fire stations: This data was extracted using Google earth, by searching for ‘Fire Stations’ in Dalarna. The search results were digitized and exported into a .kml (keyhole markup language) file. This file was then converted in to a Shapefile using ArcGIS tools. Figure 7 shows output when Euclidean distance was used to create raster rings.
Fig 6: Current medical facility with Euclidean distance buffers indicating increasing radial distance rings from existing service.

Fig 7: Fire stations with Euclidean distance buffers indicating increasing radial distance rings from fire station.
Step 3: Questionnaire

After the above layers are created, each and every layer has to be assigned a certain weight of influence on the final output. These weights come from step 4, that is, Analytic Hierarchal Process (AHP). AHP is a process that is non-statistically based, and is made for the decision making process. While the process was initially made for a single user, it can even be used with a sample size including more participants (Duke M & Aull-Hyde, 2002). Hence as an input to the AHP, certain preference values for pair wise comparisons between each factor is required. To obtain these pair wise comparisons for five factors, 10 questions were created. All the questions covered a pair wise comparison of every factor with every other factor. This questionnaire was distributed to healthcare professionals as well as urban planning professionals.

Finding weights for factors for the creation of a mobile hospital were limited, due to less available of literature in the field. However, multiple papers that have studied the selection of medical facilities (Rahimi, Goli, & Rezaee, 2017), as well as other domains (Kuo, Chi, & Kao, 2002) have either found weights from readily researched literature reviews, or fresh questionnaires. Hence, this approach of generating a questionnaire, targeting fields of experts form range of domains affecting medical site selection was done.

The questions contained marking of an importance between a pair of two factors across the scale of -0 to 8, with 0 being the value of equal importance. The scale for the pair wise comparison makes use of Saaty’s scale that ranges from 1 to 9, where 1 is of equal importance and 9 means one factor is much more important than the other factor (Zhang, Liu, & Yang, 2009).

The aim of this questionnaire is to find pair wise relative importance between all factors, so that it can be input into the next step of AHP. A total of 15 forms were sent out, with 7 returned.

Step 4: Analytic Hierarchical Process

AHP, as mentioned in the previous step, stands for analytic hierarchal processing. It was proposed by (Saaty, 1980). It is a decision making technique in a structured format which is based on the hierarchal framework using pair wise comparisons. This is done mathematically. The aim of this is to derive weights for every decision making criteria from the pair wise
comparisons of importance between two criteria. This is repeated until all the criteria is compared with each other. The paper (Vargas & Satty, 1991) provided a scale for comparisons where a degree of importance is assigned to every value on the scale, which is represented in Table 2. To represent inverse relationship is reciprocal of the numbers are used.

Table 2: Table for pairwise comparison (Saaty T. V., 1991)

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
</tr>
<tr>
<td>5</td>
<td>Strong or essential importance</td>
</tr>
<tr>
<td>7</td>
<td>Very strong or demonstrated importance</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values</td>
</tr>
<tr>
<td>Reciprocals</td>
<td>Values for inverse comparison</td>
</tr>
</tbody>
</table>

Convert an unstructured problem into a structured one by clearly defining the aims and requirements of the results to be expected (Wu & Zhou, 2012).

1. Set factors or layers that will influence the complicated problem.
2. Make use of pair wise comparisons between all of these criteria and create comparison matrices.
3. Use methods like eigenvalue to find relative weights of the criteria.
4. Work out the consistency ratio for the matrices and make sure it falls within the limit of weight settings.
5. Find out the weight settings that are most appropriate to eventually receive overall rating for every criterion.

For this study, an open source AHP template for multi participant decision making was used. The excel sheet provided by (Goepel, 2013) sheet consists of number of weights, scale and number of participants. For this study 7 participants, 5 criteria and Saaty’s scale 1-9 were used (Saaty, 1980).
Step 5: Reclassification and Weighted Overlay

Solving a multi criteria problem consists of multiple layers/factors, where each layer has to be provided a weight of influence. The final output generated is a combination of all the weights with the layer values. Weighted Overlay function is hence one of the commonly used functions when solving an overlay analysis with multiple criterion (ArcGIS-Weighted Overlay function, 2020).

In the terms of GIS, weighted overlay combines multiple layers of raster data that use a common scale of preference, and weigh each layer and each layer is weighted according to its relative importance: (Vlek, Lamers, Khamzina, & Rudenko, 2014)

\[ S = \sum_{i=1}^{n} (w_i \times v_i) \]

Where,
- \( S \)= Land user suitability
- \( i \)=layer number
- \( n \)=number of layers
- \( w_i \)= weight of layer \( i \)
- \( v_i \)= value of layer \( i \)

(*= symbol for product)

An illustration provided below in Figure 8 can pictorially explain how the Weighted Overlay works. Every layer has individual pixel values. The whole layer has an overall weight. The Score for a pixel X across multiple layers will be the sum of value of x on each layer, multiplied by weight of each layer (Weighted Overlay, 2020).

![Image](image.png)

Fig 8: Graphic representation of working of weighted overlay (Weighted Overlay, 2020)
In the real world, when multiple factors have to be overlain, they are seldom present in the same scale or range of classification. Hence, to proceed with a weighted overlay, these individual factors/layers must be reclassified to a common scale. This scale can range from 1-10 or -1 to 1 among others, given the type of analysis. This is a relative scale, wherein a value of 4 is preferred twice more than value 2. (ArcGIS-Weighted Overlay function, 2020). In this study, every layer from step 2 is reclassified to a common scale of 1 to 5, using the ArcGIS Reclassify tool. Table 3 shows the scale used.

Table 3: Classification scale value based on priority of class

<table>
<thead>
<tr>
<th>Scale Value</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Medium Low</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>Medium High</td>
</tr>
<tr>
<td>5</td>
<td>High</td>
</tr>
</tbody>
</table>

Hence, layers that initially consisted of multiple classes, as shown in step 2, are now reclassified to 5 classes each. This can be seen by a comparison of the Bus proximity layer before and after reclassification. Before, the bus layer is classified into 11 classes, as in Figure 9. These are then reclassified to 5 classes as shown in Figure 10. Class 5 being 100 meters close to the bus stops, and class 1 being beyond 1.2 km to the bus stops. Here, hence, closer to the bus stops, higher the priority, and further to the bus stops, reduction in priority. Such a reclassification is done to every layer. This is explained pictorially in Figure 11.
Fig 9: Vector euclidean distance for Bus Stop

Fig 10: Raster reclassification for bus stop

<table>
<thead>
<tr>
<th>Multiple Classes</th>
<th>RECLASSIFY</th>
<th>5 Classes</th>
<th>Apply Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity to Bus</td>
<td>Proximity to Bus</td>
<td>W1</td>
<td></td>
</tr>
<tr>
<td>Proximity to Road</td>
<td>Proximity to Road</td>
<td>W2</td>
<td></td>
</tr>
<tr>
<td>Population Density</td>
<td>Population Density</td>
<td>W3</td>
<td></td>
</tr>
<tr>
<td>Proximity to Fire Station</td>
<td>Proximity to Fire Station</td>
<td>W4</td>
<td></td>
</tr>
<tr>
<td>Distance from Existing Services</td>
<td>Distance from Existing Services</td>
<td>W5</td>
<td></td>
</tr>
</tbody>
</table>

Output Combination Raster Layer with Overall score ranging from 5 (best) to 1 (worst)

Fig 11: Working of reclassification and weighted overlay
Hence, over all the final sub step of this sub step consists of first, converting every layer into classified layer on a scale of (worst) 1-5 (best). These layers are then input into the weighted overlay. The weights of the weighted overlay are determined from the weights generated from the AHP output.

**Step 6: Location Allocation of Facilities to Demands**

When there are multiple facilitates that have the ability to provide goods and services to a given distribution of demand locations, Location Allocation can be used to find those facilities that supply the demand locations with utmost efficiency. This method is a multifold method, which narrows down and picks the best facility points, and also assigns demand points to it. Hence, Location Allocation picks out the best ‘n’ locations from an input dataset (Tomintz, Clarke, & Nawaf, 2015).

For this study, once the Weighted Overlay process is carried out, all the locations across the county that meet a 5/5 and 4/5 score in every Factor are extracted. In total 15 facilities have to be placed ideally in these areas. Hence, use of the Location Allocation tool by ArcGIS is made, since it chooses the best locations from a set of input locations.

**Input to Location Allocation Demand Points:** The demand points for the location allocation are all the population points that have not been covered in a 10 km radial buffer by the already existing services. These left out population pockets are the target audience that has to be allotted the facilities.

**Input to Facilities:** Regions that received 5/5, 4/5 score from the output areas of step 5 are extracted. This will provide 2 dimensional polygons of the area with scores of 5 and 4. Throughout this polygon, any point contains a 5 or 4 suitability value for a mobile hospital. Hence, a point within these polygons has to be the ‘facility’ point. Thus, these polygons are populated with sample points of 1 km interval in X and Y direction. Each of these sample points act as potential demand points. This sampling of points at every 1 km interval allows a wide
region to be assessed as a ‘facility’ across its entire area, at ample intervals, rather than selecting a single centroid or a mean weighted center as the ‘facility’ for that whole area.

The Location Allocation tool works on the principle of repeatedly analyzing multiple ways in which the combination of Demands can be assigned to facilities. This permutation and combination run until all facilities are assessed for the number of demands they cover, along the ‘road’ radius, and not the ‘radial’/’aerial’ distance. Those facility points are picked that minimize overall travel distance. This travel distance is measured using the ‘Roads’ dataset as ‘Lines’ along which the demand will travel to reach the facilities. A set number of 15 demands are set on the tool, due to which the tool picks up the 15 best possible demands from all the inputs. Also, an Impedance limit of 10km is set. This means that the Demands will only show the area it will facilitate in 10 km travel distance.

4. Results

Step 1: Delineating Factors for the study
The factors presented in Table 4 were narrowed down on, based on availability of data/capability of producing data, and literature review. The respective references of papers in which each factors importance is discussed are also provided in the table.

<table>
<thead>
<tr>
<th>Factor Number</th>
<th>Factor</th>
<th>Factor Name</th>
<th>Data</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Accessibility</td>
<td>Proximity to Public Transport</td>
<td>Buffer around Bus Stops</td>
<td>(Ahadnejad, et al., 2015)</td>
</tr>
</tbody>
</table>
Step 2: Data Sources and Processing
The results for this step are discussed with the Methodology section: Step 2 itself. This is because the methodology describes the processing of the data that was done, and placing its results (the results for this section are in the form of figures 3-7) in the methodology allows a more systematic lucidity in reading for the readers.

Step 3: Questionnaire
The Survey form was sent out to 15 professional experts, and 7 were returned. The profile of participants that filled out the form are mentioned in Table 5 below.

<table>
<thead>
<tr>
<th>Field</th>
<th>Specialization</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medicine</td>
<td>Ambulance Nurse</td>
<td>1</td>
</tr>
<tr>
<td>Medicine</td>
<td>Intensive Care Unit Nurse</td>
<td>1</td>
</tr>
<tr>
<td>Medicine</td>
<td>General Nurse</td>
<td>1</td>
</tr>
<tr>
<td>Medical Administration</td>
<td>Investigator/Analyst</td>
<td>1</td>
</tr>
<tr>
<td>Medicine</td>
<td>Surgeon</td>
<td>1</td>
</tr>
<tr>
<td>Urban Planning</td>
<td>Urban Planner</td>
<td>1</td>
</tr>
<tr>
<td>Urban Planning</td>
<td>Urban Planner</td>
<td>1</td>
</tr>
</tbody>
</table>
Step 4: AHP Results

Given the varied distribution in domains of expertise, results by the urban planners differed from those working in the medical field. The presence of more participants could have helped to agglomerate the results with better consistency among all participants.

The overall consistency ratio received was 0.6. For a matrix of the size 5*5, and 7 participants, a consistency ratio can span up to 0.3-0.4. The Matrix was generated for the 5 factors, with the Normalized Principle Eigenvector values at 30.1%, that is the highest, for Transport Stop proximity, followed by Proximity to Residents as a close second at 27.72%. Next came Roads proximity, Fire Station Proximity and Distance from existing service, in that order. The matrix and eigenvector values can be viewed in the Table 6 below.

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Existing Service Proximity</th>
<th>Roads Proximity</th>
<th>Transport Stop Proximity</th>
<th>Fire Station Proximity</th>
<th>Resident Proximity</th>
<th>normalized principal Eigenvector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Service Proximity</td>
<td>1</td>
<td>1</td>
<td>7/8</td>
<td>3/8</td>
<td>1</td>
<td>3/8</td>
</tr>
<tr>
<td>Roads Proximity</td>
<td>2</td>
<td>1/7</td>
<td>1</td>
<td>1/2</td>
<td>1/4</td>
<td>5/9</td>
</tr>
<tr>
<td>Transport Stop Proximity</td>
<td>3</td>
<td>2/3</td>
<td>1 8/9</td>
<td>1</td>
<td>1 6/7</td>
<td>1 1/7</td>
</tr>
<tr>
<td>Fire Station Proximity</td>
<td>4</td>
<td>1</td>
<td>4/5</td>
<td>1/2</td>
<td>1</td>
<td>3/5</td>
</tr>
<tr>
<td>Resident Proximity</td>
<td>5</td>
<td>2 3/4</td>
<td>1 4/5</td>
<td>7/8</td>
<td>1 5/8</td>
<td>1</td>
</tr>
</tbody>
</table>

It is observed that a 1/3rd influence weight is assigned to the Transport Stop proximity, and hence, it is considered as one of the most important requirements by majority users. The Proximity to population is also a close 2nd, in importance. These are the two most influential factor, with a larger margin compare to the rest of the factors.

The +/- of the Weights and the weights can be viewed in the Table 7 below.
Table 7: AHP resultant weights for each layer/factor

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weights</th>
<th>+/-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing-Service Proximity</td>
<td>12.2 %</td>
<td>1.6 %</td>
</tr>
<tr>
<td>Roads Proximity</td>
<td>15.6 %</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Transport Stop Proximity</td>
<td>30.0 %</td>
<td>2.1 %</td>
</tr>
<tr>
<td>Fire Station Proximity</td>
<td>14.5 %</td>
<td>2.0 %</td>
</tr>
<tr>
<td>Resident Proximity</td>
<td>27.7 %</td>
<td>3.5 %</td>
</tr>
</tbody>
</table>

The final ranking of the factors is in the order: highest- Transport Proximity> Resident Proximity> Roads Proximity> Fire Station Proximity> Distance from Existing Service. The margins of difference can be viewed in the Figure 12 given below. As viewed, Roads Proximity, Fire Station Proximity, Distance from Existing Service have almost equal weights.

Fig 12: Relative weight comparison of all layers/factors

Step 5: Weighted Overlay Results

The weights from the AHP table are inserted into the Weighted average analysis, for each reclassified layer. Hence, every pixel on every layer has a certain score after reclassification, which is multiplied by the weight of its respective layer. The output is a resultant raster map of the Dalarna region, where each pixel has an output overall score of 5-0, 5 being best, and 0 as
not applicable. The pixels that showed a score of 5 in all of the original reclassified layers, will sum up to an overall weighted score of 5, and similarly, for 4. And those pixels that showed bad values in individual layers, overlay to get low weighted overlay score of 1.

The final resultant overlay raster layer is observed to have values ranging from 5, 4, 3, 2 and 0, and is viewed in Figure 13 and 14. Hence, this means, that no pixel falls in an overlap that is bad. Only medium bad, medium, medium good and good pixels are present. The remaining ‘0’ pixels are ‘Restricted’ values. This means that these values are so unfit, that they cannot be allotted a score. Hence, they are completely unfit for the location allocation.

![Weighted overlay result with classes](image)

Fig 13: Weighted overlay result with classes
The 5 score values in red are seen to be dispersed across the southern and eastern parts of the County. This is the region that has majority hold of the big cities, resident, and population density, and yet, the red regions have proved to be uncovered by any previously present facilities within 10km. Hence, these red regions have the best site suitability for an upcoming mobile hospital. We also observe that the red regions are relatively low in count in the western and northern parts of the county. If only the red regions, that is, regions with a score 5 are considered suitable, a major loss of resident coverage can take place in western areas. Hence, even the next best, that is, a score of 4 in yellow colour is considered as suitable areas.

Step 6: Location Allocation

For a further narrowed down analysis of location, the 5 and 4 score values from Weighted overlay output were extracted. These areas covered wide regions of land. The aim for this step was to further narrow down the suggested locations for the mobile extent to a high resolution of X/Y level on ground.
For this, as mentioned in step 6 of Methodology, sample points were generated throughout areas having 5 and 4 scores, with 1 km interval in X and Y direction. Fig 15 and 16 shows the consequent potential facility points that were created.

Fig 15: Score 5 and 4 from weighted overlay: used to create sample Facility points
The sample points were generated within each of the polygons. These are the ‘Facilities’. They are represented in a zoomed in view in Figure 17 as blue points.

The location allocation tool was run, as discussed in the methodology, with 1106 input facilities, and 3667 demand points. The impedance was set at 10 km, which means the location allocation
tool would not search for facility coverage beyond 10km. The top best 15 such output facility points were generated, in a way that maximum coverage of demand points was covered. These demands are shown in purple against green facilities in Figure 18.

![Figure 18: Location allocation resultant Demand and Facilities covered](image)

Service area was generated, which are polygons that show the travel distance of 10km covered by each facility along the road. In the following Figure 19, it can be sampled that all the points of Demand in a cluster, have been covered in a radius of 10 km Service area by their respective Facilities. Figure 19 shows facilities in purple, and population points in green dots. The service area of 10 km for the facilities are in grey.
Population Covered

The final population covered by the suggested mobile hospital covers an additional of around 28,288 citizens, after meeting all the demands from the weighted overlay, in addition to being in a minimized travel time of 10 km. Of these, 7959 are aged above 65 years of age.

![Population Uncovered Before and After Analysis](image)

Fig 20 Graph of population coverage before and after analysis
The total population covered facility wise and elder citizen wise is provided in Table 8. Also, latitude-longitude of the final suggested 15 mobile hospital locations is presented in Table 9. Figure 22 shows a map of newly suggested mobile hospital location, along with already existing medical facilities.

Table 8: Population covered by each newly suggested facility

<table>
<thead>
<tr>
<th>Facility Number</th>
<th>Facility ID</th>
<th>Points covered</th>
<th>Total population above 5 years covered</th>
<th>Total population covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74</td>
<td>130</td>
<td>921</td>
<td>3702</td>
</tr>
<tr>
<td>2</td>
<td>81</td>
<td>140</td>
<td>582</td>
<td>1911</td>
</tr>
<tr>
<td>3</td>
<td>171</td>
<td>135</td>
<td>655</td>
<td>2411</td>
</tr>
<tr>
<td>4</td>
<td>174</td>
<td>62</td>
<td>184</td>
<td>818</td>
</tr>
<tr>
<td>5</td>
<td>364</td>
<td>78</td>
<td>201</td>
<td>809</td>
</tr>
<tr>
<td>6</td>
<td>377</td>
<td>79</td>
<td>300</td>
<td>1228</td>
</tr>
<tr>
<td>7</td>
<td>397</td>
<td>133</td>
<td>248</td>
<td>1048</td>
</tr>
<tr>
<td>8</td>
<td>417</td>
<td>140</td>
<td>605</td>
<td>2119</td>
</tr>
<tr>
<td>9</td>
<td>573</td>
<td>212</td>
<td>921</td>
<td>3409</td>
</tr>
<tr>
<td>10</td>
<td>582</td>
<td>255</td>
<td>1296</td>
<td>4982</td>
</tr>
<tr>
<td>11</td>
<td>721</td>
<td>203</td>
<td>584</td>
<td>2228</td>
</tr>
<tr>
<td>12</td>
<td>793</td>
<td>138</td>
<td>601</td>
<td>1874</td>
</tr>
<tr>
<td>13</td>
<td>829</td>
<td>100</td>
<td>356</td>
<td>1252</td>
</tr>
<tr>
<td>14</td>
<td>849</td>
<td>71</td>
<td>163</td>
<td>383</td>
</tr>
<tr>
<td>15</td>
<td>919</td>
<td>153</td>
<td>342</td>
<td>1114</td>
</tr>
</tbody>
</table>
Table 9: Position co-ordinates of suggested new locations for Mobile Hospitals

<table>
<thead>
<tr>
<th>Facility Number</th>
<th>Facility ID</th>
<th>X (° E)</th>
<th>Y (° N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>14.95710852</td>
<td>60.077919</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15.58606149</td>
<td>60.0766279</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16.43786685</td>
<td>60.24074036</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>16.2395976</td>
<td>60.25172017</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>14.04697329</td>
<td>60.47857146</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>15.77524685</td>
<td>60.47972308</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>14.46506693</td>
<td>60.49886073</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>14.7926627</td>
<td>60.5087503</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>15.8727163</td>
<td>60.72155362</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>15.43295669</td>
<td>60.73267298</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>15.7465091</td>
<td>60.81210181</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>14.53217387</td>
<td>60.89416555</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>13.3697355</td>
<td>60.92102326</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>13.97768649</td>
<td>60.94496852</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>15.17805675</td>
<td>61.05646411</td>
<td></td>
</tr>
</tbody>
</table>

Fig 22 New suggested locations vs existing medical care locations
5. Discussion

As seen from the results above, an addition of 15 mobile hospitals in the given locations covers around 28,288 people, along with meeting other requirements from the aim such as accessibility (method used: AHP criteria ‘Roads, Public Transport, Fire Stations’ in Weighted Overlay), maximum population coverage (method used: AHP criteria ‘Population Density’ in Weighted Overlay), maximum travel distance of 10 km (method used: Location Allocation ‘impedance’ set to 10 km), and that these newly covered populations are not already covered by an existing medical facility (method used: AHP criteria ‘Existing Service’ in Weighted Overlay, setting the Location Allocation Demand points as the population currently uncovered by existing services).

Initially, before the placement of the mobile hospitals, the total number of uncovered population was 45,888 which have gone down to 16,600 after placing 15 mobile hospitals. This is a net increase in 62% of coverage. This number is still not covering 38% in comparison to the number uncovered initially. However, the spread and scarcity of populations in some regions is such that even if the hospitals placed there cover more ‘population points’, the total sum value of ‘number of people’ covered will be less compared to the current scenario. The methodology adapted in this thesis has tried to cover the next ‘best’ 15 areas, which will allow the highest coverage compared to any other areas. Although it may feel like many clusters remain uncovered within 10 km, and that is true, it must be kept in mind that those uncovered clusters are too widely scattered in space, with respect to total population contained by them, as compared to the clusters covered.

The use of a Network dataset that contains Road edge and nodes, and impedance of travel distance in the analysis ensures that travel distance is considered while making decisions. The Location Allocation tool in combination with Service areas creation validate that a minimum travel distance of 10 km is fixed, and it also makes sure that travel beyond this distance is not made. By using layers such as distance to roads and public transport, accessibility is also covered. Further, by using a population density layer, in combination with population based Location Allocation analysis allows the ‘population’ factor to be involved in the final decision. It can be observed that the newly suggested hospital facilities are close to the urban areas, and near the existing facilities, but with a distance of 10 km between them. In the scenario that the coverage for existing facilities would be extended to 15 km or 20 km, the newly placed hospitals
would shift to more rural or suburban regions. This is because the dense population from the urban areas in the 10 km-20 km band will already have been considered as covered.

It is also observed, that there are very scarce existing facilities to the north of the county. This is because of the sparse scatter of population there. If one hospital was to be built in that region in the centre of the scatter, a distance of much more than 10 km would have had to be travelled by the residents. Hence, 2 or more mobile hospital would be required to meet the requirements of the aim for such regions. Hence, to counter this imbalance, a proposed study could be to carry out two separate analyses, one for the rural and scarce scatter regions, where different travel distance and weighting rules apply, and a different analysis for more dense urban population.

It is observed, that in the scenario the travel time of the existing facilities as well as the new facilities is increased by 1 km-2 km each, a substantial change is visible in coverage, and it would require less than 15 mobile hospitals to attain maximum coverage. The funding for the extra leftover mobile hospitals can be adjusted towards the rural areas.

A miscellaneous observation that was made while working on this study area is that the presence of large water bodies significantly affects the Road wise Service area coverage of each facility. Since most settlements are dense around the periphery of a water body, placement of a medical facility on one point of the ring deviates access to the opposite point in the same ring of water body. If linear distances are considered, such as building a bridge across the large spanning water bodies, this problem can be resolved.

Conclusions

This thesis aimed at studying locations for setting up mobile hospitals in Dalarna, in a way that maximum population was covered, with minimum and equal travel distance for all. For a problem like this, multiple factors are required to reach towards a solution, and hence, the mode chosen in such a scenario is a combination of Multi criteria analysis along with Location allocation and Service Area analysis. The multiple criteria approach ensured coverage of accessibility and population, along with issues such as proximity to public transport (for youth and non-drivers), and proximity to roads (for drivers) that play an integral part of the study. AHP helped in assigning fair weights to each of these factors and proved useful because the
consistencies between each pair could be supervised, ensuring better weights. Also, criteria such as the density of the population spread, and population as ‘Demand’ in the Location Allocation ensured weightage was given to travel distances from residences so that facilities are ‘closer’ to ‘more’ people and a bit far for few, rather than being equally far to all. Location Allocation methods allowed the possibility to pick the top 15 demand facilities that provided the maximum population coverage, while Service area allowed tracking Road wise travel distance, rather than aerial/linear travel distance. The best points that were picked in the final step of the analysis proved to have covered over an average of just below 3000 people per facility, while maintaining that every step of the methodology fulfilled the requirement of all the sub-aims.

**Limitations and Uncertainties**

One of the biggest limitations of this study was the absence of consideration of ‘age’ applied to the analysis. This was ignored to save time on the study, as data collection and processing took up more time than predicted. Another reason it was assumed safe to let go of this was because it was observed that almost every old age density cluster fell inside the total population density cluster. At a resolution of 100 square meters, it is difficult to delineate finer differences in residence patterns of different age groups. Hence, on the given resolution of data, the old age population groups were placed without any significant outliers compared to the total population, and almost always overlaid with each other.

Another limitation was the absence of data for diving directions along the roads, as well as speed limits for the roads. This can cause an uncertainty in the sense that a single direction road may not necessarily meet a drive distance of 10 km from demand to facility. There could be more lanes taken by a single way street to reach point A to B, than a street that is allowed travel in the opposite way. So, it is wrongly considered part of the 10 km service area, because other way direction allows it. Also, speed limits can greatly affect the travel time, which is at times, more efficient a parameter than drive distance, especially in urban areas. An availability of speed limits would enrich the road network dataset to provide more accurate results.
A significant limitation discussed previously in the step 3 of the methodology is the low number of responses from experts and professionals. A bigger sample size would ensure more consistency, and truth in the weights. It would also ensure a better Consistency Index.

A municipality-based study was considered initially, rather than county based. However, this would restrict the travel of a citizen from municipality A living near boundary of municipality B, closer to the medical service of municipality B. This would not be an ideal scenario as all citizens are allowed to visit the medical facility most convenient for them.

Another limitation to this study is generating relevant sensitivity and necessity tests for each factor. These would allow recognizing which layers is the analysis actually sensitive to, and also, pick out those layers that are significantly necessary for the analysis. Due to shortage of time, this analysis could unfortunately not be made, but can hopefully be covered in future studies.

Another technique is using different analysis model for different types of regions of the county. Given that the population spread in the county is dense around Borlänge, Falun, Mora, Ludvika, and scarce towards the north, separate analysis factors and weights should have been implemented for the difference in the environments.
References


Mikaniki, J., & Sadeghl, H. (2013). Location of medical-health centers (hospitals) in Birjand city through a combination of network analysis process (ANP) and paired comparisons by GIS. Birjand: Environmental Based Territorial Planning.


Weighted Overlay. (2020). Retrieved May 23, 2020, from ArcGis:


Appendix A

This appendix section contains the questions asked in the questionnaire. Saaty’s scale was adjusted from 1-9 to 0-8, and the reciprocal importance as 0 to -8.

As a part of my Masters Thesis at Dalarna university thesis: A study of Location for Mobile Hospital, I am conducting a survey that investigates the importance of surrounding factors affecting site selection for medical care units. I will appreciate if you will complete the following survey, based on your knowledge and experience in the field. Any information obtained in connection with this study that can identify with you will remain confidential.

Field of Work:
Highest Level of Education Relevant to Medical care/Planning:

Rank 5 factors in order of Importance: For site suitability of Medical Service

1. What is more important for building a new medical center: being closer to a Road, or that it is far away from an already existing medical center?
2. What is more important for building a new medical center: being closer to a Public Transport stop (train station/bus station), or that it is far away from an already existing medical center?
3. What is more important for building a new medical center: being closer to a Fire Station, or that it is far away from an already existing medical center?
4. What is more important for building a new medical center: being closer to Residents, or that it is far away from an already existing medical center?
5. What is more important for building a new medical center: being near Roads, or that it is near Public transport stops (train/bus stations)?
6. What is more important for building a new medical center: being near Roads, or that it is near a Fire Station?
7. What is more important for building a new medical center: being near Roads, or that it is near Residents(people)?
8. What is more important for building a new medical center: being near Public transport stops (train/bus station), or that it is near a Fire Station?
9. What is more important for building a new medical center: being near Public transport stops (train/bus station), or that it is near Residents(people)?
10. What is more important for building a new medical center: being near Fire Stations, or that it is near Residents(people)?