Strategic Placing of Field Hospitals Using Spatial Analysis

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Abstract

Humanitarian help organisations today may benefit on improving their location analysis when placing field hospitals in countries hit by a disasters or catastrophe. The main objective of this thesis is to develop and evaluate a spatial decision support method for strategic placing of field hospitals for two time perspectives, long term (months) and short term (weeks). Specifically, the possibility of combining existing infrastructure and satellite data is examined to derive a suitability map for placing field hospitals. Haut-Katanga in Congo is used as test area where exists a large variety of ground features and has been visited by aid organisations in the past due to epidemics and warzones.

The method consists of several steps including remote sensing for estimation of population density, a Multi Criteria Evaluation (MCE) for analysis of suitability, and visualization in a webmap.

The Population density is used as a parameter for an MCE operation to create a decision support map for locating field hospitals. Other related information such as road network, water source and landuse is also taken into consideration in MCE. The method can generate a thematic map that highlights the suitability value of different areas for field hospitals. By using webmap related technologies, these suitability maps are also dynamic and accessible through the Internet.

This new approach using the technology of dasymetric mapping for population deprival together with an MCE process, yielded a method with the result being both a standalone population distribution and a suitability map for placing field hospitals with the population distribution taken into consideration. The use of dasymetric mapping accounted for higher resolution and the ability to derive new population distributions on demand due to changing conditions rather than using pre-existing methods with coarser resolution and a more seldom update rate.

How this method can be used in other areas is also analysed. The result of the study shows that the created maps are reasonable and can be used to support the locating of field hospitals by narrowing down the available areas to be considered. The results from MCE are compared to a real field hospital scenario, and it is shown that the proposed method narrows down the localisation options and shortens the time required for planning an operation. The method is meant to be used together with other decision methods which involves non spatial factors that are beyond the scope of this thesis.
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1.- Introduction

1.1- Background

Humanitarian help organisations today may benefit on improving their location analysis when placing field hospitals in countries hit by a disasters or catastrophe. A high percentage of the population in these countries are not accounted for at aid camps (Wladis 2009) since a large number of people probably reside in such a way that the current placing of the aid camp is beyond their reach.

Independent help organisations today seldom use a geographic analytic perspective when considering placing camps and the methods used previously have been based on local knowledge, previous visits and experience from people associated with the organisation at that time. The most common problems with methods that do not use geographic analysis are that they do not summarize scattered information from various sources in an efficient way. This might lead to increased duration of the planning procedure. Locations that may be ideal for placement of field hospitals might also be overlooked without an objective geographical analysis.

The main goal of this study is to develop a toolkit for the strategic placing of aid camps using geographic analysis to accelerate the planning process. Another purpose is to generalise some of the methods that are used to obtain the result for the specific test area. These generalised methods may then be used in other areas.

Early and strategic intervention is also essential in a public health perspective. For an epidemic type catastrophe, the number of reported cases will increase exponentially until intervention with medical care is implemented (Fig.1.1). Therefore, the proposed may be useful to improve the health conditions of an area by accelerating the planning process of field hospitals.

![Fig. 1.1. Reported measles cases in Niamey, Niger November 2003- July 2004.R. F. Grais et al, 2008.](image)

When placing aid camps, it is necessary to know how many people it will reach approximately in order to plan the need for food, water, medicines and other supplies. In areas with unknown or diffuse population distributions it is difficult to estimate these needs. It is also important to be able to rule out areas with steep terrain and lack of usable roads which might make transportation impossible. Water is
also important for the placing of hospitals since it is hard to transport in larger quantities. Without this information, aid camps might lack the effectiveness if they could have with a more optimised placing.

The focuses of the problem are estimating population distribution and obtaining a useful representation of this data at higher resolution for planning aid camps. This can be achieved by creating a gridded population data (Jordan, 2007). The population distribution is then used as a parameter for the placing of the camp. The possibilities with visualising different important features needed for these camps together might be beneficial in comparison to collecting different sources of information separately.

A study of an outbreak response in Niger 2003-2004 was conducted comparing different approaches using simulations. It was found that intervening early (up to 60 days after the start of the epidemic) and expanding the age range to all children aged 6 months to 15 years may lead to a much larger (up to 90%) reduction in the number of cases in a West African urban setting like Niamey (Fig.1.2). This timely intervention may save more lives if started before the exponential increase of the epidemic.

![Fig.1.2. Estimated proportion of cases averted with a vaccination intervention targeting children aged between 6 and 59 months for a vaccination intervention lasting 10 days: The blue line shows an intervention at 60 days, the red line an intervention at 90 days and the green line an intervention at 120 days. R. F. Grais et al, 2008](image-url)
1.2- Research Objectives

The overall objective of this thesis is to develop and evaluate a spatial decision support method for strategic placing of field hospitals for two time perspectives, long term (months) and short term (weeks). The specific objectives are:

- Develop a method for generating field hospital suitability maps based on geographic parameters.
- Evaluate the use of the suitability map by placing field hospitals according to the demands of running field hospitals.
- Publish the suitability maps in a dynamic webmap.
2. Literature Review

MCE has been used in different applications such as site allocation, land use selection and crises management. It is a suitable tool for field hospital selection. The population distribution is important because it is essential that field hospital placement is close proximity to a large amount of people in need of aid. This section will start with a short summary of general uses of MCE technologies today, following reviews of how MCE is used as a part in larger decision support systems. Part 2.2 will discuss different types of data collection methods and different types of MCE methods related to crisis management, especially the population distribution discovery. Finally, visualization and presentation methods are reviewed.

2.1- MCE applications

2.1.1- General applications

Spatial MCE application has a wide area of uses and some common applications can be divided into the following basic categories (Herwijnen et al.2005).

Site selection/allocation

Classify and rank a set of sites in priority order for a specific use. If a school or a particular type of business is needed in a community, what site might best be suitable for that activity? Selection between a few or many suitable areas is made. Location allocation problems means having two or more sets of interrelated decision variables. A typical example for these location and allocation variables is to locate a new rural health clinic so that the most of the population is within a certain amount of traveling time from the nearest clinic. The site of the health clinic is the location variable which is dependent on the allocation of people.

An example of this is a study of marine fish cage site selection made in Tenerife 2001 with water quality parameters. The water quality variables identified were: temperature, turbidity (runoff soil erosion and sewage), disease stress (sewage) and possibility of waste feedback from fish-cages (bathymetry). These were used in a MCE model to generate the most suitable areas for sitting cage culture. Most areas along the coastline were deemed suitable and none was identified as unsuitable(Pérez et al. 2001).

Land use selection

Property owners might be unsure as how to utilize a specific site, and hence need to classify and rank the uses in priority order for that site. It answers questions such as how a specific land parcel may be used effectively in a selection between many alternatives.

In 2003 a study was made applying land use selection for rating of different agricultural alternatives in Doiwala India. Alternatives of agriculture were rice, sugarcane, maize, vegetables, horticulture and pulses. Parameters for the MCE model included infrastructure, population, temperature, rainfall, irrigation and the chemical/physical qualities of the soil. Rice was found suitable for a dominant part of the research area(Prakash T.N 2003).
Land use allocation

If a fixed amount of land is to be used, how can one optimize the allocation of land areas for specific land uses. For example, "How much of the land should be allocated for the following uses: forestry, recreation, and wild life.

An example of this methodology is a case used in the Netherlands 2002 and was focused towards allocating suitable land areas towards dairy farming (Fig.2.1). First, all areas not suitable were disregarded. Then, each dairy farm was mapped to the characteristics of future prospects. Size of the farm area and number of livestock was among the characteristics examined. The next step focused on the accessibility of farmland to nearby farm buildings. For each area unit, the five nearest farms are selected that lie within a radius of 2500 m of the area unit. If distances are larger, the assumption is made that no extra profit will be gained. The distances between each grid cell and the five selected farms are then calculated, using the current road network. Proximity buffers around the road network provide the distance from a grid cell to the nearest road. The calculated distances, that represent the accessibility of a grid cell, are added up by weighted summoning. The future potentials of the farms provide the weights. This resulted in the value of each area unit, in regards to future dairy farming. By creating buffers around each farm where the buffer size is dependent on the farm characteristics, future land parcels with potential for conversion to dairy farming could also be graded (Gerrit et al. 2002).

Fig.2.1. Land use allocation. Potential farmstead parcels for a highly productive dairy farming type (left), and an extensive dairy farm type (right). Dark colors represent farmland with a high probability to be claimed by future dairy farming.
2.1.2- MCE related applications in Crisis management

MCE methods are used in various fields such as economics and other statistical branches. However, when used in crisis management, the adding of geographically-defined objectives is beneficial (Moamed A.AL-SHALABI et al. 2006). Spatial features which are important for Multi criteria evaluation in crisis management will vary a lot depending on the catastrophe. Infrastructure, land-use, elevation and population however are frequently mentioned (Moamed A.AL-SHALABI et al. 2006, Müller et al.2010). These methods are often meant to be used in decision support systems when trying to minimize the effect of the disaster. These so-called Spatial Decision Support Systems (SDSS) can be seen as an umbrella for systems that integrate the MCE analysis with spatial temporal data and other models to produce decision aid (Müller et al.2010). An SDSS is an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial problem (Fig.2.2). It is designed to assist the spatial planner with guidance in making land use or other spatial related decisions. For example, when deciding where to build a new facility with contradicting criteria, such as noise pollution vs. employment prospects or the knock on effect on transportation links, which make the decision difficult. A system which models decisions could be used to help identify the most effective decision path. The system structure is made of three key fundamental subsystems.

(1) A database management system that stores and handles geographical data. This system can in itself be divided into a storing and management/retrieval part. A standalone system with these components is also sometimes called GIS(Geographical Information System).

(2) Models/algorithms that can utilize this spatial data to calculate forecasts of possible decision outcomes. These models can also utilize non-spatial together with the spatial data.

(3) The last part is an interface which a user can interact with and receive a visual interpretation of the analysis result.

![Fig.2.2. SDSS structure](image)
In these SDSS, the actual MCE part is contained within the model/algorithm section of the system as a chain of the necessary consecutive process executions using spatial and sometimes non-spatial data as well (Müller et al. 2010). Following below are some examples of different SDSS systems.

**MOLAND**

The aim is to provide a spatial planning tool for development of urban and regional events. It was initiated in 1998 to monitor development of urban areas and trend analytics on the European scale (Fig.2.3.). The work includes the computation of indicators and the assessment of the impact of anthropogenic stress factors with a focus on expanding settlements, transport and tourism both in and around urban areas (European Commission 2011).

![Fig.2.3. Moland Schematics(European Commission).](image)

**LUMOCAP**

LUMOCAP aims at delivering an operational tool for assessing land use changes in Poland and Germany/Netherlands (Fig.2.4.). These land use changes was controlled by a common agricultural policy where the core was a land use Cellular automata model (European Commission 2011).
HCDSS-(Health Care Decision Support System)

Methodology for a system which is designed to identify the hazardous nature of transport-related air pollution on health (Madhuri et al. 2010). This will allow decision-makers to combine personal judgment with computer output. It can be divided into three main parts (Fig.2.5).

(1) Database Management
With the main purpose of preparation and pre-processing of all input data, the bulk of all data is also filtered to each needing subsystem.

(2) Knowledge-base Management subsystem
Contains all the knowledge for rule management such as retrieval, update deletion etc. It communicates with the Data Management Sub-System via an integration interface for knowledge updating. User can drop their latest information and knowledge in this part of the system which will then be used in the analysis algorithms and MCE procedures.

(3) Central decision making desk
Contains a collection of programs used for the decision making process. These can furthermore be divided into two sub-categories.

Sub Quality control program
This program selects a suitable rule from the knowledge base and extracts the needed facts along with suggestions for decision making.

Sub Quality analysis tool shell
Contains the MCE analysis shell comprising of a model-base knowledge system which accepts the data from the database, interacts with other health care informatics modules, calculated and presents the result through two systems called the Central Vision Exhibit board and the Dialog management subsystem. The first is the platform which combines all systems both internal and external while the latter contains interface and visualization/presentation logic.
2.2- MCE related technologies

2.2.1- Data collection

MCE analysis makes use of several different branches of data collections depending on what spatial problem to be solved. Some of these are listed below.

Landuse

Landuse and other ground properties are frequently used parameters for MCE analysis. Satellite remote sensing and aerial photography are common ways to gather this data. Satellites and airplanes often carry multispectral scanners to retrieve data across more than one electromagnetic band. This way of gathering data makes it possible to analyse features based on their representation in multiple electromagnetic bands. Remote sensing is often used to map land use.

Different software can then be used to classify different features on the image based on their spectral signatures. In a method called unsupervised classification, the ranges of spectral signatures are
clustered into a number of classes based on their closeness to each other in each of the bands. It is then up to the analyst to estimate what each class represents on the image.

In supervised classification, small sample areas are chosen for each of the features on the image needed to be retrieved. The algorithms then work the entire image to find signatures close or similar to these sample areas for categorisation. In general, one can say that supervised classification is suitable when the analyst has knowledge of the image area and knows the common features present there (Lillesand, et al., 2004, ch; 7).

**Infrastructure- roads cities**

Infrastructure such as roads, villages and cities may have a wide variety of sources and depending on the area to be analysed, also a diversity in quality. Munipacility offices or international agencies may provide this data which is often gathered through field measurements or sometimes through remote sensing such as aerial photography or satellite imaging.

**Topology- elevation- height**

Data containing height information are often used in MCE processes. Laser scanning, or high altitude radar scanning are common methods for large area coverage. In airborne laser scanning, the position of the plane is tracked through a GPS(Global Positioning System) and the relative height to the ground is calculated by the travel time of the laser beam from emitting to returning(Fig.2.6).

![Fig.2.6 Aerial laser scanning](image)

In satellite scanning, Interferometric synthetic aperture radar or ISAR uses differences in the phase of the waves returning to the satellite to receiving topology information. The Shuttle Radar Topography Mission (SRTM) was an international endeavor that used this technology to yield a 80% world topology coverage with 90m resolution(SRTM, 2009).
2.2.2- Population Distribution

The environmental datasets today connected to population distribution are mostly consisting of course spatial datasets. This demographic data is collected from administrative census units which only contains approximate total population within the respective district border and thus have a very coarse resolution. In recent years, researchers have started to develop new methods to refine the population grid both globally and regionally, since the need for spatial allocation from the large census units into regionally consistent population grids has increased throughout the years.

Gridded Population of the world

The first effort to obtain a globally consistent population dataset was the GPW(Gridded Population of the World) as shown in Fig.2.7 (Balk and Yetman, 2004). It is produced at NCGIA(National Center for Geographic Information Analysis) in 1995 and updated by CIESIN(Center for International Earth Science Information Network) in 2000. The data for this method was administrative boundaries and the population estimates connected to these (Balk, et al., 2006). A recent version of this has even included land cover and urban population calculations.

Summary

- Global Coverage and availability

- Low Resolution Connected to administrative units up to 1km

![Fig.2.7. Gridded Population of the world](image)

LandScan

Another study was the LandScan Global Population Database, produced by the Oak Ridge National Laboratories (ORNL), which distributes national populations by land cover category, according to a
model with assumed coefficients for population occurrence in each type of land cover. It had a better resolution since the distribution was more accurately calculated using this new data (Fig. 2.8).

The initiatives following this incorporated satellites imagery, infrastructure and land use classification maps. Other recent efforts include calculations to refine urban areas using the night time lights globally (Balk, et al., 2006).

The above methods used for calculating the distribution of people is useful for large area analysis, however the resolution is not high enough when considering areas containing a district or smaller country.

**Summary**

- **Global Coverage and availability**
- **Fixed Resolution 1km and Costly**
- **Only updated once a year**

![Fig.2.8. LandScan Global Population Database, adjusted to UN figure year 2000](image)

**Dasymetric Mapping – used in this thesis for population derivation**

Dasymetric Mapping was developed by Russian cartographer Semenov Tian-Shansky and the American cartographer J.K Wright (Mennis, et al., 2006). Dasymetric Mapping uses an ancillary dataset to reapportion data from a larger choropleth map zone into smaller units to refine the resolution. The most common application is population distributions but it can be applied to any other punctiform data which can be modelled as a statistical surface. In general, the data values in the new units are based on different conditions such as other overlapping features for that specific unit. These units receive weights, which determine how large part of the original value they receive (Holloway, et al., 1997; Mennis, et al., 2006). A pilot study was conducted to map urban land cover by fusing GPW, elevation, infrastructure and land cover classification. (Schneider et al. 2003). The goal was to extract population distribution in Zimbabwe using Dasymetric mapping. The purpose of this was to get a
more detailed overview of where people are living compared to current estimates. It was intended to be used in planning aid programs in countries affected by different kinds of catastrophes. The resolution was reported increased by a factor of ten compared to Landscan data. By adding the infrastructure e.g. roads, villages and cities to the land cover data, they distributed the population more realistically (Fig.2.9, Fig.2.10).

![Diagram of Dasymetric mapping in population derivation](image)

**Fig.2.9. Dasymetric mapping in population derival**

This method used in this thesis to obtain the population distribution parameter for the Multi Criteria Analysis has a higher resolution than previous methods and is easier to incorporate in the overall analysis. Data for this type of method is easily retrievable than other methods while still promising good results and high accuracy. Other population data such as LandScan that exists on a global basis, but it is subject to defined resolution of 1km. In the Dasymetric mapping method developed in (Schneider et al. 2003), data availability determines the final result.
Summary

- Adjustable resolution depending on data availability
- Update on need
- Cost is dependent on data
- Data gathering might be time consuming

2.2.3- Analysis methods

General approach

The process of building models to aid problem solving involving multiple criteria problems have been examined since the early 60:s. MCDA or Multi criteria decision aiding have many different methods for handling multiple objectives but the most widely used one is the so-called “goal programming technique”. Each of the objectives in this multiple objectives problem have given set goals to achieve. The optimum solution to the problem is then defined as the state where the least deviance from these goals occurs (Malczewski et al.1990). This method was later developed and generalized to something called the reference point approach (RPA) introduced by Wierzbicki 1982. The RPA can be described by this basic workflow.

(1) The decision-maker specifies his requirements and acceptable values for each given objective.

(2) The decision-maker works interactively with a computer so he can change his requirement level during the analysis.

(3) The computer system provides the decision-maker with the most effective solution given his objective requirements.
To assess any given multiple objective problem, it is important that the decision maker is experienced in formulating the relative importance of the requirements in step (1). There are many methods of expressing the requirement and their relational importance. The Analytic Hierarchical process (AHP) is a theory measurement that uses pair wise comparison together with expert judgement in order to quantify the importance of each objective (Fig 2.12).

This becomes important in cases where there is a potential of conflicting interests. A scale of 17 numbers is used ranging from 1/9 to 9. Each objective requirement are given a value on this scale in relation to each other objective. A decision matrix is formed using these values where the diagonal values are the pair wise comparison of each objective to itself.

![Pairwise Comparison Matrix](image.png)

**Fig.2.12. AHP approach example. Source: www.sfu.ca**
From this matrix, a consistency ratio is calculated which should not exceed 0.10 in order to be acceptable. Another method of applying values in step one is called the MACBETH method (Measuring attractiveness by using a categorical based evaluation technique). It is an MCDA approach requiring only qualitative judgement of the difference of values in each objectives attractiveness over another (Figueira et al. 2005). It tries to coherently aggregate qualitative evaluations using an additive utility model.

A more direct rating of options in MCDA is to distribute 100 “importance points” over the different objectives (Borcherding et al. 1991). This method is suitable when the objectives do not contradict themselves. This method requires a qualitative approximation of each objectives importance. In this type of method, the experience of the decision-maker to quantify his objective requirements becomes even more important. If step (1) consists of explaining these requirements to an analyst, the communication also becomes very important. The method suggests to first defining two anchors of the scale with their numerical importance on a scale of say 0-100. Preferably, the least attractive and the most attractive. The other objectives are then given values between those two anchor objectives (Carlos et al. 2004). This method of assigning direct values of importance to the objectives through communication with decision-maker was used in this thesis. Conventional MCE or MCDA methods have largely been non-spatial. They use average or total impacts that are considered appropriate for an entire area under consideration. Fundamental to spatial decision problems is location. Location transcends the wide variety of spatial decision problems. A spatial overlay is often used to represent this location part where the different parameters add or withdraw from the final result by adding their weighted values to each unit inhabiting the same space (Fig 2.13). A spatial problem typology is based on an interest in addressing one of the following questions.

1. Given a desired activity, which sites might be best for that activity?
2. Given an occurrence, which area or areas is that occurrence most influential.
3. Given a site or sites, what kind of activity might be most suitable there?

![Image](image_url)

Fig. 2.13. Example of a simple spatial overlay procedure.
In crisis management it is possible to divide the analyze purpose of the MCE into two general categories, Vulnerability analysis and Localization of emergency actions. The latter can be regarded as a form of MCE Site selection.

**Vulnerability analysis**

Vulnerability analysis in crisis management means to assess which feature will be affected and how strong the effect of the disaster will be and is related to Risk-assessment (Raquel Libros Rodríguez, Yolanda Pérez Dorado, 2009). There is a variety of focuses in this part of the field but it is common to create models based on comparison parameters. In the case of natural-disasters the following steps can be used.

1. Simulate the spatial extent of a disaster without any early warning system present.
2. Compare the previous effects to if there had been an early warning system
3. Simulate the effect if there had been an optimal warning system present.

Research has been conducted with the aim of estimating tsunami vulnerability. In classification of ground features using satellite data, elevation thresholds and distance analysis is important in these cases when performing vulnerability analysis using Multi Criteria Elevation. The example in Fig.2.14 aims on smaller areas and localised disaster type .The vulnerability analysis reveals areas in danger of tsunami damage. In Fig.2.15 another result of an MCE vulnerability analysis is shown where the focus is on water contaminants.

![Fig.2.14. Tsunami Vulnerability analysis using MCE (Raquel Libros Rodríguez, Yolanda Pérez Dorado 2009)](image-url)
Fig. 2.15. MCE process showing potential degree of threat to population due to contaminant exposure (Müller et al. 2010).

Localization of emergency actions - Site selection

Crisis management also so means to cope with the aftermath of a disaster. In an SDSS Localization of emergency actions such as strategically place field-hospitals is therefore crucial to avoid unnecessary harm (R. F. Grais et al, 2008, Schneider et al. 2003). The decision support system takes a different focus in this case and tries to assess the needs required for an aid facility to achieve it´s goal. Previous work regarding localization of similar facilities has focused on smaller urbanized areas in the intention to improve effectiveness of permanent hospitals regarding cost and population load, such as the “central facility problem “ (Fig.2.16) described in (Malczewski et al 1990). Facility placement tries to maximize the user benefit and suppliers cost using a predefined set of suggested hospital locations as well as the location of existing hospitals. In this case the following objectives were considered.

- Minimization of the aggregate travel cost for the population.
- Maximization of the level of users’ satisfaction for a location pattern of hospitals.
- Minimization of the investment costs.
- Minimization of the operating costs.
- Minimization of the environmental pollution at hospital sites.
Each objective is minimized or maximized separately for each objective using information retrieved for each location. The multi criteria problem yields a result for each of the locations considered for each of the objectives.

![Multiobjective Location of Hospitals](image)

**Fig.2.16. Multiobjective Location of Hospitals (Malczewski et al. 1990).** 1. Administrative boundary; 2. administrative boundary; 3. allocation of patients to hospitals; 4. administrative center of areal units; 5. size of hospitals; 6. Existing hospitals; 7. new hospitals.

When not considering predetermined locations in multi criteria problems, more recent studies use the method of spatial overlays to yield suitability values for different objectives according to their spatial distribution. The method are mostly used for permanent house or facility placement but the overlay procedure can be extended to mobile field hospitals as well.

Here, the main problem is discussed and then criterias and constraints are formulated which are expressions of the requirements and preferences of the placement. After this, an analysis of each criterion importance is retrieved either using an AHP approach or other method such as MACBETH or simply distributing importance points. For house site placement, the MCE process may focus on finding a limited amount of appropriate locations or categorizing a larger area with suitability values which is sometimes called “Land suitability assessment”. Land suitability assessment is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area (Senes, Toccolini 1998). The suitability map surface can be calculated by overlaying different layers representing each objective in the MCE process(1).

\[
\text{Suitability Map} = \sum (\text{factor map}(cn) \times \text{weight}(wn) \times \text{constraint}(b0/1))
\]  

\(cn = \text{Standardized raster cell,}\)  
\(wn = \text{Weight derived for the factor}\)  
\(b0/1 = \text{Boolean map with values 0 or 1}\)
This process is often used in site suitability studies where several factors affect the suitability of a site. (Esri, 2000). The GIS overlay process is calculated for each cellular value on a raster dataset which combines the factors and constraints in the form of a Weighting Overlay process. The result is then summed up producing a suitability map as shown by Fig.2.17. This method is used in this thesis for mapping the suitability surface for mobile field hospitals.

<table>
<thead>
<tr>
<th>Title</th>
<th>Author</th>
<th>Used in this thesis</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>An Interactive Approach to the central Facility Location Problem: Locating Pediatric Hospitals in Warsaw</td>
<td>Jacek Malczewski, Wlodzimier Ogryczak</td>
<td>No</td>
<td>Dynamic Interactive Network Analysis System</td>
</tr>
<tr>
<td>Gis Based Multicriteria: Approaches to Housing Site suitability Assessment.</td>
<td>Moamed A.Al-ShALABI et al. 2006</td>
<td>Yes</td>
<td>Suitability map using MCE</td>
</tr>
<tr>
<td>Reduction of a Hospital Network as a Multiple Criteria Optimisation Problem</td>
<td>Ludmila Janošiková 2009</td>
<td>No</td>
<td>Optimize hospital location in urban areas.</td>
</tr>
<tr>
<td>Multi Criteria Evaluation for Emergency Management in Spatial Data Infrastructures</td>
<td>Müller et al. 2010</td>
<td>No</td>
<td>Determine areas at risk of chemicals using MCE, vulnerability analysis.</td>
</tr>
<tr>
<td>. Population Estimation in Developing Countries.</td>
<td>Stefan Schneiderbauer, Daniele Ehrlich, 2005</td>
<td>Yes</td>
<td>Population derival using Dasymetric mapping</td>
</tr>
<tr>
<td>Sustainable land use planning in protected rural areas in Italy</td>
<td>Giulio Senes, Alessandro Toccolini, 1998</td>
<td>Yes</td>
<td>Suitability maps using MCE</td>
</tr>
<tr>
<td>Tsunami Vulnerability analysis using MCE</td>
<td>Raquel Libros Rodríguez, Yolanda Pérez Dorado 2009</td>
<td>No</td>
<td>Vulnerability analysis using MCE</td>
</tr>
</tbody>
</table>

Table.2.1 MCE and Population method summary
2.2.4- Visualization of results

When visualizing results of spatial analysis, today’s industry has gone towards physical maps to digital maps and onwards to dynamic digital maps and web map cartography. All of the above formats are still much in use, but when it comes to SDSS (Spatial Decision Support Systems) the methodology often present the graphical result of an analysis such as an MCE in the form of a web map solution (Müller et al. 2010). The two main components in these web map solutions are server and client. The server(s) are used to compute the analysis and generate images that are sent through the OGC (Open Gis Consortium) standard called WMS (Web Map Service) to the user client. These images are dynamic in the sense that the user can pan, zoom and also add overlapping data from both internal and external sources. For more functionality, a WFS (Web Feature Service) can be implemented. This OGC standard allows sending actual feature data as individual parcels for presentation. This can be used for modifying, editing searching data that would otherwise be a view only image. As standard physical and other static maps most likely will still have its use in many cases, there are some benefits with using web map technologies for distributing analysis and other information in a SDSS system.

- Deliver up to date information
- They are often independent of the client system
- They integrate both the data produced with already existing data from various sources dynamically
- Easy to distribute data to all decision group participants

There are of course situations where there are they may present some problems such as bandwidth issues, reliability issues and limited functionality compared with a standalone local application installations. Some local applications however, include the functionality to retrieve this data through WMS/WFS and then process data using the applications own tools.

An example of this is LST (Länsstyrelsen) in Sweden which is using this technology to visualize their gathered data in combination with other data (Fig. 2.18). It is used both internally (with extended functionality) and as a public viewer tool for everyone. In these services data such as environmental factors are distributed through the wms server but can also be downloaded for specific professional user with access.

Fig. 2.18. WMS browser interface. Environmental atlas LST, Sweden (Source http://www.gis.lst.se/)
3.- Study Area and Data Description

3.1- Test Area Haut-Katanga

Haut Katanga is located in the south eastern region of The Democratic Republic of The Congo. It is approximately 200,000km² which is half the size of California and 7 times larger than Belgium (Fig.3.1). The area has a large variety of ground features and has been visited by aid organisations in the past due to epidemics and warzones. The diversity of ground features are beneficial in order to test if the results of the methods are adequate despite generalisation of landuse and elevation. This makes it a good sample area for the analysis.

The province of Haut-Katanga originated from a subdivision of Katanga into four parts in 2009. It is restless area with small groups of ex-militia, hunger and disease spread out in different parts.
3.2- Data

Data consisted of raster, vector and statistics from various sources. Table.3.1 explains the datasets and their origin.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Type</th>
<th>Year accumulated</th>
<th>Origin/retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villages/Cities</td>
<td>point layer, shape files</td>
<td>2007</td>
<td>Le Référentiel Géographique Commun (<a href="http://www.rgc.cd">www.rgc.cd</a>)</td>
</tr>
<tr>
<td>Distrikt Border</td>
<td>vector layer, shape files</td>
<td>2007</td>
<td>Le Référentiel Géographique Commun (<a href="http://www.rgc.cd">www.rgc.cd</a>)</td>
</tr>
<tr>
<td>Landuse Map</td>
<td>Digital static map, tif file</td>
<td>2008</td>
<td>Belgian national Museum</td>
</tr>
<tr>
<td>Elevation</td>
<td>DEM, Digital elevation model, Grid files</td>
<td>2008</td>
<td>Nasa(90m height grid)-National Aeronautics and Space Administration (NASA)- 2002 SRTM (Shuttle Radar Topography Mission)</td>
</tr>
<tr>
<td>Population data</td>
<td>Statistical</td>
<td>2007</td>
<td>Union de Congolais pour la Défense de la Patrié et du 31eople (UCDP) Statistical estimate</td>
</tr>
<tr>
<td>Landscan2008 sample image</td>
<td>Image</td>
<td>2008</td>
<td>LandscanTM</td>
</tr>
</tbody>
</table>

Table.3.1. Dataset
3.2.1- Roads and villages

The roads and villages datasets were derived from both DCW (Digital charts of the world), interviews with locals, and night time lights. Region border of Haut-Katanga was also derived from the same sources. By using the ESRI Software ArcMap, the district border was used to clip both roads and villages to limit the amount of data to the actual workspace. The data was all projected in World Mercator with the geographic coordinate system WGS 1984. Fig.3.2 and Fig.3.3 illustrate the full dataset and the clipped result after minimizing it to the working area Haut-Katanga Congo.
Fig.3.3 Clipped dataset containing roads and cities/villages of work area Haut-Katanga

3.2.2- Satellite Imagery

Ten landsat scenes were used to cover the test area. They consisted of nine spectral bands which were processed in ArcMap as a composite band tif file and then exported as an image file from ArcCatalog for use in Erdas Imagine.

Fig.3.4 Satellite imagery-Landscan
3.2.3- Digital Landuse

A digital land use map (Fig.3.4) covering a portion of the central Haut-Katanga area was used as a crossreference of the classification and also to retrieve to common types of land use present in the area. It was imported into ArcGIS and georeferenced for easy comparison with the created landuse.

3.2.4- Elevation

The elevation data is consisted of two raster images with the slope represented in percentage. The Digital elevation model originated from a 90m height grid.

No transformation was needed since it was defined in the same coordinate system as the road and villages dataset. These two images were also put together to form a mosaic over the same extent as the rest of the datasets.
4.- Methodology

The research involved three main steps. Firstly, a Population Distribution was created covering the study area Haut-Katanga using dasymetric mapping. Secondly, the population distribution was used in a Multi Criteria Evaluation to calculate a field hospital suitability map for long term (more than 6 months) and short term stay (weeks). Thirdly, these static maps were incorporated in a dynamic webmap for increased usability and planning purposes.

Fig.4.1.Method procedure
4.1- Method for Population Distribution

The prepared data was put together for population distribution evaluation and comparison. The following data was assembled for the analysis.

- Infrastructure: Roads, Cities, Villages and Hospital
- Satellite imagery
- Digital Elevation Model
- Hydrography
- Total Population Estimates

The different datasets have been described in chapter 3. Weights presented in the chapters are based on (Stefan Schneiderbauer, Daniele Ehrlich, 2005. Population Density estimation for Disaster Management).

4.1.1- Remote sensing analysis

The first part of the analysis involved Remote Sensing using landsat imagery. Remote sensing is when data are gathered using a device that is located far away from the actual feature.

It is often used when information over a wide area such as Haut-Katanga is needed. Satellite remote sensing are common ways to gather this data. Satellites often carry multispectral scanners to retrieve data across more than one electromagnetic band. This way of gathering data makes it possible to analyse features based on their representation in multiple electromagnetic bands. Remote sensing is often used to map land use. The data is gathered and refined for a Geographic Information System Software. Some software focus on analysing multispectral images retrieved from different forms of remote sensing such as Erdas Imagine.
4.1.2- Land use mapping by Supervised Classification

In remote sensing, the obtained data is often in the form of a multispectral image from a satellite or airplane. Different software can then be used to classify different features on the image based on their spectral signatures. In unsupervised classification, the ranges of spectral signatures are clustered into a number of classes based on their closeness to each other. It is then up to the analyst to estimate what each class represents on the image.

In supervised classification, small sample areas are chosen for each of the features on the image needed to be retrieved. The algorithms then work the entire image to find signatures close or similar to these sample areas for categorisation. In general, one can say that supervised classification is suitable when the analyst has knowledge of the image area and knows the common features present there (Lillesand, et al., 2004, ch; 7).

When mapping the land use in the study area, supervised classification was used and the emphasis was placed on four essential categories that have a great importance on population distribution. These are urban areas, bush/woodland, communal farmland and large water areas.

Signatures were created for each of these categories (Fig.4.2). These training areas were selected both by using the digital land use map covering a portion of the test area and also by visually inspecting GoogleMap areas with high resolution aerial photos. The test areas were chosen from each of the different scenes to account for different contrast conditions.
More categories than intended for use in the final calculation was needed to improve the quality of the supervised classification. The categories urban, bush, communal farmland, savannah, water, damp vegetation were retrieved in the supervised classification and then aggregated into urban, bush/forest/savannah, communal Farmland and water. After aggregation the data was imported into ArcMap and converted to an Esri grid file.

![Fig.4.3. Aggregated classes after supervised classification on the satellite mosaic using Erdas Imagen Demo license](image)

**4.1.3- Weighting of Landuse**

The resulting land use map in Fig.4.3 was verified using the digital landuse map which covered a subpart of the total test area. The Esri gridfile created earlier was reclassed using the spatial analyst with the weights 60 for urban areas, 8 for farmland, 1 for bush/forest and zero for large water areas. The water areas were created to act as a constriction parameter in the analysis as described in chapter 1. By using the raster calculator in spatial analyst it was clipped to the extent of the Katanga test area.
4.1.4- Creating and weighting buffers

Rocks

Roads were classified into large/medium and small by aggregating classes in the original dataset. These consisted of national, regional priority, regional secondary and local roads. Buffers were created with the size 300m and 100m respectively, based on the assumption that population density increases in close perimeter to roads. (Schneiderbauer, et al., 2005)

The buffers were creating using ArcMap buffer tool. The output was a shape file which needed to be converted into raster format for use in the overlay procedure (Fig.4.4).

Fig.4.4. Buffered roads in the Lubumbashi area, thicker national and thinner local roads.

Following the creation of buffers, different weights were assigned to the cell units in the raster layer. Units were assigned the weight 5 if they were passing through bush/forest areas and 20 if they were passing through areas with farming. This was done by overlay with the landuse raster. Different layers were created that only included those areas of the roads that were intersecting farming, and bush/forest respectively.

The part of the roads that were within the classified urban areas were assigned the weight of 60, same weight as in urban areas The weighting values were then assigned to a value column in the attribute
table using the ArcMap spatial analyst reclassifier. All other areas for each layer that were outside the intersection were given value zero for easy addition with the other layer.

The different pieces of the road buffer raster where then added together using the spatial analyst raster calculator to form the roads parameter with different weights on the cell units according to the underlying land use. The parameter now included a raster layer with road buffers of different weight, depending in their intersection with the urban, communal farming, bush/forest (Fig.4.5).

Fig.4.5. The Roadbuffer parameter with different weights depending on the intersections with landuse.
Cities and Settlements

Since the settlements/city areas are of great importance for population density, buffers were also created in a circular radius around these features dependent on their approximate size. The raw dataset had more categories than needed for this analysis which is similar to the roads.

The Original categories were Head of province, head of district, head of territory, head of sector, important village and other smaller villages. These categories were aggregated into a smaller number. Two weight categories were set for the cities, 60 for the three larger ones and 20 for the three minor village types.

The buffers around each original category were created as 1500m, 1000m, 600m, 300m, 200m, 100m respectively while the weighting values were aggregated to 60 for the three larger city features and 20 for the three smaller village types to generalize the number of classes into the weighting categories suggested by Stefan Schneiderbauer. Buffers were rasterized individually by category and set to the same extent as the test area. The individual raster layers that represented each of the settlement categories where added together in the ArcMap spatial analyst raster calculator to form a dataset with all the settlements with respective weight and buffer size (Fig.4.6). All values outside the buffers were assigned the weight zero for later addition with the other datasets.

Fig.4.6. Buffers around settlements and the rasterized dataset with assigned weights including east border feature.

Elevation

The elevation mosaic was reclassified to form a data layer that could act as a division parameter in contrast to the other addition layers. Weighting of the different values were divided into three categories based on the percentage of slope each cell unit represented. The slope 0-10 percentage was given weight 1, 10-20 percentage weight was given weight ½ and 20 percentage and above was given weight ¼. This weighting was inversely proportional to the other weights so that multiplication with other layers would decrease the value at cell locations with step elevation.
4.1.5 - Overlay of weighted features

ArcMap was used to integrate all different layers into a weighted density map. It was done by using the raster calculator to add the values of each independent dataset into a combined raster. Each cell in this raster contained a value describing the amount of importance in relation to number of people. The cell size was 100m in accordance to the other layers for reasonable and manageable calculations.

The process for deciding which weight an individual cell would receive was decided according to a flowchart model (Fig.4.7). First it was decided if the cell existed within a buffer. If that was the case, it would receive the weight of the buffered feature. If it existed within several buffers the weights was added together. The cells that were located outside a buffer were given their weight in accordance to land use. The water areas were incorporated in the land use and were given weight 0. The elevation datasets was used at the final stage for division with the weight values.

The ArcMap spatial analyst raster calculator was used to perform the operation and the process of deciding which cells that was located within/without buffers was also done manually when preparing the overlay datasets. Overlap areas, such as road buffers and city buffers were added together. When road features existed within the boundaries of classified urban areas they were given the same weight as the urban areas. The city buffer feature overlapping urban areas were not added together but were explicitly treated as part of urban and received the same weight. For summarisation of the weight procedure, see (Fig.4.8).

Fig.4.7. Overlay procedure resulting in Distribution of population weights.
Fig. 4.8. Decision tree for the overlay weighting procedure.
The generated density map was used to distribute the total population in the area which was approximately 4 million. The weight for each cell was represented in the data value column connected to the raster set. The Formula for population allocation according to weight value presented in (Schneiderbauer, et al., 2005) was used.

\[ \text{pop}(i, j)[D] = a_D \times \text{pw}(i, j) \]  

(1)

In the formula (1), \( \text{pop}(i,j)[D] \) is the number of estimated people located within the area of pixel \((i,j)\). The symbol \( a_D \) is a constant computed for the whole district as shown in formula (2) and \( \text{pw}(i,j) \) is the weight of the current pixel.

\[ a_D = \frac{\text{pop}[D]}{\sum \{\text{pw}(i, j)\}} \]  

(2)

In the formula (2), \( \text{pop}[D] \) is the total estimated population value over the test area. The symbol \( \text{pw}(i,j) \) is the weight of pixel \((i,j)\). The constant \( a_D \) is computed by taking the total estimated population over the area and divide it by the sum of the weights in the area. The output is the constant \( a_D \) which is a ratio between weight and number of people. This ratio is a representation of how many people each unit of weight yields.

After this process, the resulting population distribution was reclassed to give absolute values rather than ranges which is standard in the spatial analyst. The extent of the population was set to the extent of the test area, Haut-katanga polygon (Fig.4.9).
Fig. 4.9. The population distribution parameter displaying number of people per individual cell unit.
4.1.6- Validation

By using a sample image from Landscan 2008 covering the Lubumbashi region, the result of the population density could be compared. The increased resolution in Fig.4.10 reveals additional details not covered by the landscan 2008 sample.

Fig.4.10. Top- Population distribution results, 100m resolution.  Fig: Bottom- Landscan 2008 sample image of 1km resolution(Max resolution for Landscan is 1km).
Existing approximate population counts were used to evaluate the dasymetric result. By calculating the number of people within each sample area and compare them to the existing population count the values in Fig.4.11 was retrieved. Since the existing data is an approximate count, comparison with the true value becomes difficult.

4.2.- Multi Criteria Evaluation

The second step of the analysis used a MCE evaluation to combine the population distribution layer with the previously mentioned factors that are important for field hospitals locations.

Multi Criteria Evaluation is a method where several different features are weighted together into an analysis to present an overall outcome. In the spatial field, the location of different features and their values present additional viewpoints which make MCE suitable when the optimum placing of a certain feature is needed based on different factors and constraints.

Constraints are conditions which are not acceptable such as water, if it is a case where the localisation cannot take place there. Factors are weighted features of importance to the analysis and can for example be areas with certain distance to roads or areas lying on certain type of soil. These factors are
represented on individual map layers usually in raster format. All different factor layers have ratings within the same interval which are then multiplied by the weight/importance of respective feature. These layers are then summed together to create a final map displaying the graded result of the analysis (Fig.4.11). The criterions are used to remove areas which are not suitable (Longley, et al., 2005, ch; 16).

![Diagram showing the MCE procedure](image)

An interview was made with field hospital researcher Andreas Wladis at Karolinska Institutet to determine these important parameters. The following parameters and their relevance were verified to match the basic needs of a field hospital: accessibility to water, access to roads, electricity, estimated population reach, distance to airport and finally avoidance of steep terrain and large water areas (Table.4.1). The weight of each parameter and the relative number of importance was decided. These parameters could be derived by using the data already put together in step 1.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility to water using local rivers, lakes</td>
<td>Transportation of water is expensive</td>
</tr>
<tr>
<td>Access to roads larger roads</td>
<td>Transportation of supplies needs to be effective</td>
</tr>
<tr>
<td>Likelihood of Electricity in the area</td>
<td>For longer durations, portable electricity is expensive</td>
</tr>
<tr>
<td>Population reach</td>
<td>Estimation of where the needs are</td>
</tr>
<tr>
<td>Distance to airport</td>
<td>Reduce unnecessary transportation distance</td>
</tr>
<tr>
<td>Avoidance of steep terrain, large water areas</td>
<td>Inaccessible areas are not interesting</td>
</tr>
</tbody>
</table>

Table 4.1 Parameters important for placing field hospitals

4.2.1- Preparing the MCE parameters

Neighbourhood layer

The population distribution parameter was used as the basis for the creation of the neighbourhood layer. This layer was created as a representation of how many people could be reached from each cell unit in a set radius of 5km. The neighbourhood statistics tool in the spatial analyser was used to implement that.

The algorithm was set to summarize the cell values from the population distribution in a circular radius around each target cell. The output cell resolution was set to 100m, same as the population distribution layer. The produced Neighbourhood layer was then reclassed to displayed Natural breaks for distinction between areas with small difference in population reach (Fig.4.13).
Distance to Roads

A straight line distance calculation was made on the roads using ArcGIS to obtain a representation of road importance.

Ten classes were used and each of the steps represented 500 meters up to a maximum of 5 kilometers from the roads. The values were set to 10 for the closest and it lowered for each step by 1 unit down to zero, above 5 kilometers (Fig.4.14).
Distance to Airport

A similar procedure was used to calculate distance to airports within the area. Ten classes were used ranging from 10 being closest and progressively down to zero above 200 kilometres. Each step represented 20 kilometres (Fig.4.15).

Likelihood of Electricity

The likelihood of electricity use, including both grid and of grid methods tend to increase in larger and more urbanized areas in contrast to rural and deep rural areas (Karki et al 2002, G Prasad et al 2007). This assumption was used to calculate a generalized map featuring likelihood of electricity. This layer was retrieved by extracting the cities and settlements of a large enough urbanization having higher likelihood of access to electricity. The categories included head of province, head of district, head of territory and head of sector. The rural classes of villages and other smaller villages were ruled out due to lesser likelihood of electricity in the area. A straight line distance calculation was performed on these selected cities were the distance to each city were divided into ten categories ranging from 10 to 1. The areas beyond 10 kilometres were given value zero and each step was 1 km (Fig.4.16).
Water Sources

Small rivers and water filled areas were used to define water sources. A straight line distance calculation was made on these with values between 10 and zero with a step of 100 meters.

Areas with a distance above 1 kilometer from any water source were given the value zero (Fig.4.17).

Elevation

Terrain with steep conditions for temporary hospital placement was defined as elevation above 10 percent (Wladis-2009, pers.com). These areas were given the value zero. All other areas were given the value 1. This steep elevation with above 10 percent elevation was seen as a constriction and given the value zero to rule them out (Fig.4.18).
Open Water

The open water areas were also ruled out by defining them as constraints. This layer was given value zero in open water areas and value 1 in the rest of the layer (Fig.4.19).

4.2.2- Weighting of factors

Weighting of the factors was done through discussing their relative importance. Since the nature of the factors were similar and follow a consistent degree of suitable- more suitable, a classical user defined method called “direct rating of options” was conducted placing them in a hierarchal scale with percentage of importance with a total sum of 100. The consistency ratio in this type will always be acceptable since there are no conflicting features. The factors are close to each other in importance and all are desirable but not required. Table.4.2 and Table.4.3 show the percentage of importance in short and long term stay.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Importance</th>
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</thead>
<tbody>
<tr>
<td>Distance to Roads</td>
<td>1</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
</tr>
<tr>
<td>Population Reach</td>
<td>3</td>
</tr>
<tr>
<td>Distance to Airports</td>
<td>4</td>
</tr>
</tbody>
</table>

Table.4.2. Weight of importance for each parameter in the short term focus.
### Table 4.3. Weight of importance for each parameter in the long term focus.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weight</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Roads</td>
<td>1</td>
<td>35%</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
<td>25%</td>
</tr>
<tr>
<td>Likelihood of Electricity</td>
<td>3</td>
<td>20%</td>
</tr>
<tr>
<td>Population Reach</td>
<td>4</td>
<td>15%</td>
</tr>
<tr>
<td>Distance to Airports</td>
<td>5</td>
<td>5%</td>
</tr>
</tbody>
</table>

### 4.2.3- Overlay Procedure

The parameters were added together using ArcMap raster calculator. Each individual layer had eleven classes with values from 0-10 based on the separate suitability. They where multiplied with their respective percentage and summarized. The constriction layers, open water and elevation above 10 percent were multiplied into this sum. These layers had value zero on the highlighted feature and value 1 for the rest of the area so that the elevation and open water areas would be subtracted from the final map (Fig.4.20 and Fig.4.21).
4.3- Finalizing the Dynamic Webmap

The suitability maps produced by the MCE analysis were used as layers in a mapserver wms to make the thematic maps more dynamic and available to users in digital format. Open layers javascript library was utilised to create the online map window and import additional wms datalayers from google and also to create additional functions such as measurement and printing possibilities. Microsoft Visual Studio was used to structure the html and javascript code for the website. The mapserver is used as the mapping engine for server calls which are processed through an apache
server. The actual website uses javascript to make the dynamic calls to the server when a user pan or zoom in the map window. The server part then sends the requested map coverage as a png image. The javascript makes it possible to send server calls requesting suitability and measurement values.

Fig. 4.22. Dynamic webmap architecture.
5.1- Results

The final analysis resulted in two thematic maps illustrating suitability surfaces for placing field hospitals in any given point within the borders of the test area. The cell resolution is 100m and the map contains the MCE suitability map with categorization 0-9 with 9 being the most ideal areas. Manual natural breaks classification was used for higher variation in areas with lower value without generalising those of higher suitability. Fig.5.1 illustrates the short term map on the dynamic website and Fig.5.2, Fig.5.3 illustrates the static maps and their legends with current known permanent hospitals displayed as symbols.

Fig.5.1. Final map displaying suitability for short term placing of field hospitals as a dynamic webmap.
Fig. 5.2. Final map displaying suitability for short term placing of field hospitals. Natural breaks classification.
Fig. 5.3. Final map displaying suitability for long term placing of field hospitals. Natural breaks classification.
6.- Conclusions, Recommendations & Future Research

6.1- Conclusions

6.1.1- Usability

The maps are meant to be used as decision support with a certain area of focus in mind. For catastrophes such as hunger, epidemics and other widespread catastrophes that do not alter the population distribution too greatly, the maps can be used successfully.

Ruling out areas with low suitability is meant to save time and effort. In conjunction with these maps it is important to have an updated knowledge of the current situation. The information should include the security level of the area. MOSS (Minimum Operational Safety Standard) is a graded scale used by the UN (United Nations) and can be applied as a measurement for the security level. This has to be acquired by the individual organisation in accordance with their needs and purpose.

When mapping large areas such as Haut Katanga, some detail might be lost in order to receive a usable map covering the whole area. One way to improve this is by mapping smaller areas where the operation is intended to take place.

The numbers of classes in Fig.5.2 and Fig.5.3 are meant to show the subtle difference that one can find in the areas with lower suitability. The test area is very large and the large span of suitability values leads to not only areas with high values and large span but also areas with low values and smaller differences. It is important to also capture these smaller differences since there might be scenarios where the high value areas are not points of interest.

As this analysis was made using only those parameters that were considered having static importance over the whole test area the resulting maps might be a little too logical to reveal any information that would otherwise be hard to find such as water contamination, road block and other changing details which are hard to derive from such large areas. In both maps the roads are an important feature when placing field hospitals. The closest proximity to larger roads without any other contributing factor yielded a suitability approximately (4.0). When tracing areas that also has overlays of water and denser population including road proximity, the suitability increases to above a value of (6.0). This can be considered a threshold value for acceptable hospital conditions and a test case was conducted to examine these conclusions in chapter 6.1.4.

6.1.2- The long and short term focus

The difference between long term and short term stay is mostly concentrated on the areas which has infrastructure or not (Fig.6.1). Large sparsely fields with long distance to permanent roads and larger villages are at a disadvantage in the long term perspective while these areas in the short term perspective have a slightly higher value. It was hoped though that the difference in these two kinds of maps would be greater but the parameter “likelihood of electricity” has an impact that is very similar
to roads and cities and a small area which often already has high values due to the overlap of the roads and cities.

![Fig. 6.1. Left, short term focus. Right, long term focus. Increased importance of areas with infrastructure and electricity can be noticed for the long term stay, while other areas are more tolerable in the short stay focus.](image)

To include a population distribution into the analysis did not have the impact originally visualised. This parameter was overshadowed by higher ruling parameters. Some gain is to be seen in low value areas with not so much infrastructure, but the importance of permanent roads make these areas unattractive when transporting supplies.

It’s however possible to estimate the number of people that can be reached at a location based on a chosen radius using the population distribution map or the neighbourhood map either as a visual comparison or by implementing it as a web feature service in the webmap. This becomes very useful when planning the placement of a field hospital.

Since the population distribution is sensitive to the temporal resolution and up to date information. These maps have a timescale in which they are useful. After this the information may become out of date dependent of change in politics, large disasters or other factors which changes the present conditions.

### 6.1.3- Error Sources

Eleven landsat scenes where used to cover the test area taken between 2001 and 2003 due to cost savings and are sources of error since they are not up to date. However, many of the features mapped are often fairly static over time-periods of a couple of years. Rivers, larger infrastructure and elevation are amongst these. The exception is agriculture which may vary slightly. Agricultural areas may change location but are often moved to patches close to the previous one and then moved back when the ground is again ready for agriculture. Some slight occurrence of this unavoidable error due to data availability and temporal resolution can be seen on the population distribution/landscan sample comparison.
Forest and semi-covered bush are sometimes mixed up in the classification. However, they were clustered together since they ultimately would have the same weight of importance. The idea of having a few parameters is also a way to counter errors that occur due to varying rules over larger areas. By selecting key features that are relatively static and general over the test area, the consistency of the map should be improved. Other features that are more detailed also have a tendency for more variation across large areas and specifically different countries. The usability of this method is increased by using the most basic and general features that have high consistency for other areas as well.

Parameters included in the analysis are usable with roughly the same relationships in different areas. If more detailed information has to be retrieved, it has to be done specifically for that region.

### 6.1.4- Test Case

In this section, actual placing of field operation will be compared with the suitability on the thematic map Long Term Stay (Fig. 6.2).

An epidemic broke out in the Tanganyika district spanning into the northern parts of Haut-Katanga. The goal of MSF (Doctors without borders) were to aid the local health care with vaccinations and isolation of the contamination. Children below the age of 5 were the most vulnerable to infection and together with acute cases these were to be prioritised. The MSF had several operations on different spots covering the two districts which were to last for about four months (MSF vaccination-campaign, 2009).

![Fig. 6.2. Left, MSF operation. Right, location of the operation on the Long Term suitability map.](image)
How does this placement correlate to the values of the Long term stay map? The area of MSF operation is compared to the Long Term Stay Map for visualization. According to the values in the right map of fig.6.2, the close proximity to water, roads and population makes the area highly suitable in the general sense. Fig.6.3 shows the actual values derived from the suitability map. Higher scores above the value of (6.0) were expected in the highlighted areas with many of the important factors present. The main reason for the placement of the temporary hospital is localisation of the epidemic and the goal of aiding the existing health care and surrounding population. Had the epidemic focus or other non geographic factors changed, any of the areas with suitability above the suggested threshold value of (6.0) might be considered for temporal hospital placement.

According to the created population distribution, the number of people living in Kilwa and the immediate surroundings are approximately 45 000 (40000 people according to Kilwa Anvil mining company). This information is very beneficial since it gives information usable for planning the amount of resources needed. As stated previously though, the maps created may also help in ruling out areas not suitable and help in narrowing down the options and also transform collections of different data sources into a more comparable and visual format. This may also shorten the early stages of planning an operation.
6.2- The problem of changing population distribution

The static map is useful for widespread disaster types when there is little chance of having a moving population due to the disaster. An example would be widespread epidemic, were the population in the area will most likely be static. However, in the case when a disaster of a certain magnitude has a centre point, affected radius and is of an extreme type, people cannot remain in the area and will have the need to flee in a direction. A war zone is an example of this. Is there a way to anticipate how the population distribution might look a certain time after the occurrence of the disaster? The Author will in this chapter explain his continued work and ideas for calculating anticipated population distribution.

6.2.1- Cellular automata and Population Disaster Flow

Cellular automata has been developed as a technology but is not yet used on a wider scale. It is based on the idea of giving cells in a raster set a few simple rules to follow and activate or deactivate them according to these rules. One Example of this is “the game of life” where cells would live if they had a certain amount of Neighbours or die if they were alone.

Experimental software has been developed by the author to initialize these ideas and test if it is possible to apply these rules for population movement. However the algorithms presented are more complicated and are based on the use of gravitational fields which will be explained in the this section.

PD Flow is based on the idea that different features have different appeal to a moving population. The disaster would be something that people will want to move away from, while cities will be something that people need for shelter and supplies. These cities/villages become more appealing the further away from the disaster they are located.

Roads are the major means of transportation and thus are attractive for people in movement of a certain distance to the road. Certain height differences can act as obstacles for people in movement and are represented as constrictions. Individual cells cannot move over these predefined elevation differences.

In the software, it is possible to define how much gravitational pull each layer of cities should have, and also how large radius that gravitational pull should be. The same applies for the roads, and of course the disaster itself which is placed and configured by the analyst. Each parameter added can in fact be configured in different ways as to what type of feature it is and what impact it should have on the simulation.

The software work in pixel image layers which have to be prepared and imported from a GIS software like ArcMap or similar. The main layer used is the static population distribution of the area at a certain time like the one created previously in the Haut-Katanga area. When the analyst run the simulation, the cells(representing population units) will start to move according to the rules and weights chosen by the analyst. The process is then stopped after a certain time interval to receive the simulation results. The purpose of this software is to test the ideas of having features of different gravitational pull or attraction forces and see if it resembles a real population distribution during or after a localised disaster. Gravitational fields are represented in raster grids, one for each parameter. The cell values in
this grid are given a higher value, from negative and up to -1 the further away for the features they are. Since each individual cell in the population distribution parameter checks its own neighbourhood in each of the other parameters, the cell will know where to move next. The direction which has the lowest value in comparison to the current cell value will be the direction the cell will move. If cell C has value 0 and neighbour n1 and n2 has -1 and -2 respectively in another gravitational grid it will choose the direction of n2 since the difference is greater. If there are two similar choices of movement the direction will be the centre point with the greatest difference between them.

This process is iterated for all cells in the population grid and the image is updated when all the cells in the grid has been calculated. The result is a live animation for the movement across the area. This technique is still being developed as an experimental project by the author but usable test software exists already.

Fig.6.4. Basic interface


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