In 2010, 304 disasters occurred. 167 of them were natural disasters which were released by Epidemic, Earthquake, Volcano, Flood, Rockfall, Landslide, Storm, Heat Wave, Cold Wave, Drought and Wildfire. 137 were man-made disasters such as war, political crisis, chemical accident or car accident. The total economic damage was 218 billion USD (Bevere et al. 2011). “In 2010, the number of reported disasters approximated the annual average disaster occurrence during 2000 to 2009 (387)” (Guha-Sapir et al. 2010). Also the number of victims increased. In 2009, 198.7 million people were affected or died which caused an economic damage of 68 billion USD. Then in 2010, 217.3 million victims were caused by natural disasters, which is less than the annual average of 2000-2009 of 227.5 million victims but the economic damage caused by natural disasters was more than 25% higher than the annual average of 98.9 billion USD (Guha-Sapir et al. 2010). The earthquake in Haiti and the flood in Pakistan had the highest impacts and wreak a huge economic damage in 2010. The year 2010 is the seventh strongest year with disasters, impacts and affected people in history since 1970 (Bevere et al. 2011). In summarizing, it can be stated that 2010 was a year of extreme weather occasions such as flood and earthquake and in Asia the highest economic damage occurred. According to Fritz Institute, a high increase of impacts and occurrence of technical and natural disasters is expected in the future (Thomas, A., Kopczak, L.R. 2005). This shows how significant and essential an effective and efficient Humanitarian Logistics and location planning is.

In order to outline the importance of Humanitarian Logistics a literature review was conducted: Kovacz and Spens determined 2007 that there were not enough research or publications in academic journals about Humanitarian Logistics; furthermore the available research publications did not indicate quantitative methodologies. The literature review in the period time of 2005 till 2010 in scientific and academic publications in journals and conferences proceeding only 7 publications focused on research methodology such as mathmatical models in Humanitarian Logistics.

As an introduction the instantaneous situation of the humanitarian operation relief chain is shown. In the second chapter the problem description is given before a location model is introduced. In the fourth chapter a solution is calculated and compared with existing response depot locations in the fifth chapter. It ends with a conclusion and an outlook. The aim of the paper at hand is to discuss the strategically and tactical decision of locations of response depots in the area of Humanitarian Logistics in case of an efficient and effective structuring of humanitarian relief operations.

INTRODUCTION

The topic Humanitarian Logistics recently becomes very important: The number of disasters has increased significantly in the last 30 years and multiplied six times between 1974 and 2010.
and Kotelba describe the inventory management in humanitarian relief, 2008 Beamon and Balciak showed an example for performance measurement, 2009 Kovác and Spens; 2010 Chandes and Pache gave an overview about the challenges in Humanitarian Logistics, 2008 Balciak et al. issued a model of last mile distribution also Vitoriano et al. gave an idea of an optimization model for humanitarian aid distribution in particular for Haiti, 2010 Balciak et al. and 2010 Taham and Kovác treat the problematic and current case besides the topic of optimization of the humanitarian response depot the coordination in the humanitarian field. The most similar paper to this research paper is the publication of Balciak and Beam in 2008 about facility location planning. The paper of Balciak and Beamon mainly implied a mathematical model for establishing a distribution network in the whole world. In their publication they develop a model that defines the number and location of distribution center in a relief network and the amount of items which can be stocked at each distribution center to supply affected people in case of disaster in a short time. The aim of this research paper is to define one main depot which can assure an effective and an efficient supply by respecting the balance between the lower transport costs, lower transit time, lowest distance to every country in the world in case of disasters. Also this research paper illustrates the idea of establishment of one central depot and it can be seen as new to most NGOs and GOs as existing research literature in this area. 

PROBLEM DESCRIPTION

First of all the definition of Humanitarian Logistics has to be presented to develop a better understanding of humanitarian operation relief and a disaster effect: A disaster occurs damage of property, human suffering and represents a disruption of society. Disaster is not only an unexpected catastrophe but the slow buildup of environmental, political, or economic factors impact on a vulnerability of a society (Plapp 2004). Hoyois et al. denote a disaster as “a situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering” (Hoyois et al. 2007). Furthermore a disaster can be seen as “an emergency of such severity and magnitude that the resultant combination of deaths, injuries, illness and property damage cannot be effectively managed with routine procedures or resources. These events can be caused by nature, equipment malfunction, human error or biological hazards and diseases” (Landesmann 2005). CRED classifies the various disaster types as followed:

<table>
<thead>
<tr>
<th>Biological</th>
<th>Geophysical</th>
<th>Hydrological</th>
<th>Meteorological</th>
<th>Climatological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disease</td>
<td>-Volcano</td>
<td>-Mass Movement (Wet): Rockfall, Landslide, Avalanche, Subsidence</td>
<td></td>
<td>-Drought</td>
</tr>
<tr>
<td>-Insect Infestation</td>
<td></td>
<td></td>
<td></td>
<td>-Wildfire: Forest Fire Land Fire</td>
</tr>
<tr>
<td>-Animal Stampede</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
for a designation of a disaster and one of them have to
be fulfilled:
- At least 10 persons were reported as death
- At least 100 persons were injured and need immediately help
- International help is needed
- Declaration the disaster as an emergency

II) The geo-coordinates of each main city affected were set as coordinates for disasters.

III) In reality the frame of the globe is an ellipse. The authors decide for a simplification of the model to assume the globe as a ball.

IV) The authors define the first urgent supplies item which will be needed in the first 72 hours in such disaster event.

V) Each weight for the first urgent supplies were found out from the items catalogue of IFRC and calculated as transport weight for each person affected (Tab.3).

After these steps following tables were finally used as input data to create a structural model and to define the necessary attribute.

Table 3: First urgent supplies

<table>
<thead>
<tr>
<th>Kit</th>
<th>Weight [kg]</th>
<th>Quantity of people for each kit</th>
<th>Weight/ Person [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>24</td>
<td>5</td>
<td>4.800</td>
</tr>
<tr>
<td>Sanitation</td>
<td>329</td>
<td>5</td>
<td>65.800</td>
</tr>
<tr>
<td>Health</td>
<td>998</td>
<td>30000</td>
<td>0.033</td>
</tr>
<tr>
<td>Tent</td>
<td>51</td>
<td>5</td>
<td>11.000</td>
</tr>
<tr>
<td>Shelter</td>
<td>20</td>
<td>5</td>
<td>4.000</td>
</tr>
<tr>
<td>Water</td>
<td>7000</td>
<td>10000</td>
<td>0.700</td>
</tr>
</tbody>
</table>

Table 2: Database for a location model and calculation

<table>
<thead>
<tr>
<th>i</th>
<th>popular name</th>
<th>main countries affected</th>
<th>date</th>
<th>type of hazard</th>
<th>main city affected</th>
<th>latitude ρ</th>
<th>longitude λ</th>
<th>people affected</th>
<th>transport weight [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Haiti earthquake</td>
<td>Haiti</td>
<td>2010-01-12</td>
<td>Earthquake</td>
<td>Port-au-Prince</td>
<td>18</td>
<td>32</td>
<td>18.33</td>
<td>18.33</td>
</tr>
<tr>
<td>2</td>
<td>Sichuan Earthquake</td>
<td>China</td>
<td>2008-05-12</td>
<td>Earthquake</td>
<td>Chengdu</td>
<td>30</td>
<td>40</td>
<td>30.67</td>
<td>30.67</td>
</tr>
<tr>
<td>3</td>
<td>Cyclone Nargis</td>
<td>Myanmar</td>
<td>2008-05-02</td>
<td>Tropical cyclone</td>
<td>Yangon</td>
<td>16</td>
<td>47</td>
<td>16.78</td>
<td>16.78</td>
</tr>
<tr>
<td>4</td>
<td>Java Earthquake</td>
<td>Indonesia</td>
<td>2006-05-27</td>
<td>Earthquake</td>
<td>Yogyakarta</td>
<td>-7</td>
<td>-48</td>
<td>-7.80</td>
<td>-7.80</td>
</tr>
<tr>
<td>5</td>
<td>Kashmir Earthquake</td>
<td>Pakistan</td>
<td>2005-10-08</td>
<td>Earthquake</td>
<td>Muzaffarabad</td>
<td>31</td>
<td>21</td>
<td>31.35</td>
<td>31.35</td>
</tr>
<tr>
<td>6</td>
<td>Hurricane Katrina</td>
<td>United States</td>
<td>2005-08-29</td>
<td>Tropical cyclone</td>
<td>New Orleans</td>
<td>29</td>
<td>57</td>
<td>29.95</td>
<td>29.95</td>
</tr>
<tr>
<td>7</td>
<td>Mumbai Floods</td>
<td>India</td>
<td>2005-07-26</td>
<td>Flood</td>
<td>Mumbai</td>
<td>18</td>
<td>58</td>
<td>18.97</td>
<td>18.97</td>
</tr>
<tr>
<td>8</td>
<td>South Asian Tsunami</td>
<td>Indonesia, etc.</td>
<td>2005-12-24</td>
<td>Tsunami</td>
<td>Banda Aceh</td>
<td>5</td>
<td>33</td>
<td>5.55</td>
<td>5.55</td>
</tr>
<tr>
<td>9</td>
<td>Bam Earthquake</td>
<td>Iran</td>
<td>2005-12-23</td>
<td>Earthquake</td>
<td>Bam</td>
<td>29</td>
<td>6</td>
<td>29.10</td>
<td>29.10</td>
</tr>
<tr>
<td>10</td>
<td>Dresden Floods</td>
<td>Germany</td>
<td>2005-08-11</td>
<td>Flood</td>
<td>Dresden</td>
<td>51</td>
<td>3</td>
<td>51.05</td>
<td>51.05</td>
</tr>
<tr>
<td>11</td>
<td>Gujarat Earthquake</td>
<td>India</td>
<td>2001-01-26</td>
<td>Earthquake</td>
<td>Bhuj</td>
<td>23</td>
<td>15</td>
<td>23.25</td>
<td>23.25</td>
</tr>
</tbody>
</table>

LOCATION MODEL

To find the facility location of one quick response depot for Humanitarian Logistics the weber facility location methodology can be used. This standard method of operations research is used to find a facility location 'in the open countryside'. The aim of this method is to estimate an optimal facility location in plane for a set of customers by using Euclidean distance measurement (Domschke and Drexl 1996).

In this research article a facility location is searched on a surface of a ball (the globe) for a set of disasters with given coordinates on the surface of this ball. Therefore it is important how long a distance on this surface between two of these coordinates is (figure 1).

Figure 1: Distance calculation methodology

Equation (1) shows the relation between the apex angle W in radian, the radius of the ball and the geo-coordinates of the points \( \{ \rho_i, \lambda_i \} \) defining W:

\[
B = \rho \cos^{-1}(\cos \phi_1 \cos \phi_2 \cos(\lambda - \lambda_1) + \sin \phi_1 \sin \phi_2) \tag{1}
\]

This distance measurement methodology has to be integrated in Weber’s facility location problem instead of the Euclidean distance measurement \( l \).

Therefore the following parameters have to be set:
- average earth radius is \( r = 6,371 \) km.
- set of customers as disasters with geo-coordinates \( (\rho_i, \lambda_i) \) in radian.
- demand \( b_i \) of each customer as weight of first urgent supplies per capita times number of people affected.

So the target function of the model is the following with the coordinates \( (\rho, \lambda) \) as target coordinates of the centralized quick response depot.

\[
\min \sum_{i=1}^{n} b_i \cos^{-1}(\cos \phi \cos \phi_1 \cos(\lambda - \lambda_1) + \sin \phi \sin \phi_1) \cdot 6371 \tag{2}
\]

This function minimizes the total transportation performance in tons kilometers for all disasters depending on the localization of the quick response depot. Since the partial derivatives of equation (2) set equal to zero cannot be solved neither for \( \rho \) nor for \( \lambda \), an analytical optimum cannot be estimated. Because for solving the Euclidean single facility
The partial derivatives of (2) with respect to $\rho$ and $\lambda$

have to be estimated:

First, the partial derivatives of (2) with respect to $\rho$ and $\lambda$

be transferred to this facility location problem on the surface

of a ball as follows:

Firstly, the partial derivatives of (2) with respect to $\rho$ and $\lambda$

have to be estimated:

\[
\frac{dF}{d\rho} := \sum_{i=1}^{n} \frac{6371 b_i \cos \phi_i \cos \rho \cos \phi_i \sin \phi \cos (\lambda \rho_i) + \sin \phi \sin \phi_i)}{\sqrt{1 - (\cos \phi_i \cos \rho \cos (\lambda \rho_i) + \sin \phi \sin \phi_i)}} = 0
\tag{3}
\]

\[
\frac{dF}{d\lambda} := \sum_{i=1}^{n} \frac{6371 b_i \cos \phi_i \cos \rho \sin (\lambda \rho_i)}{\sqrt{1 - (\cos \phi_i \cos \rho \cos (\lambda \rho_i) + \sin \phi \sin \phi_i)}} = 0
\tag{4}
\]

Then (3) and (4) have to be solved for $\rho$ and for $\lambda$ as far as possible and with the received equations (5) and (6) the

‘Miehle’-algorithm can be executed: It starts with an

arbitrary chosen set of coordinates, insert as $\rho^0$ and $\lambda^0$ and the

results $\rho^1$ and $\lambda^1$ has to be set as $\rho^0$ and $\lambda^0$ in the next

iteration step as long as the difference $\epsilon$ between $\rho^0$ and $\rho^1$ as well as $\lambda^0$ and $\lambda^1$ is smaller than a pre-defined boundary.

RESPONSE DEPOT COMPUTATION

With the developed iterative method coordinates of the facility

location of one quick response depot can be estimated and the total function value can be calculated by using assumptions and input data in tables 3 and 4. The calculation was done with the help of a ‘by-foot’ calculation within a spreadsheet. The iteration boundary was set to $\epsilon < 0.1$ and the start coordinates (-1.28333°; 36.816667°) are in Nairobi, Kenya. The boundary $\epsilon$ was reached after the 16th iteration. The estimated coordinates for a centralized quick response depot are (31.0265°; 103.7466°). Comparing this result with the input data, it can be seen that the optimal location is within Chengdu, the main city affected of the Sichuan earthquake in 2008. The reason for this is comprehensible: This earthquake affected most people by far in comparison with other disaster events so the transport performance of this disaster has so much impact on the target function that the optimal location of the depot is near to the location of this event.

Thus a decision of another computation was made to estimate the optimal facility location again, but less the data of the Sichuan Earthquake. With the remaining ten large disaster events the optimal location within the favored accuracy was reached after the 11th iteration. This time the estimated coordinates are (29.6760°; 73.3332°). This time the estimated location is in Pakistan near the boundary to India. Also this result is reproducible because in the world a few hot-spots which are susceptible to natural disasters like e.g. earthquakes according to the movements of the tectonic plates (Thomas and Kopczak 2005).

Operating performance to get the relief items with minimal resources to the disaster location. Therefore the transport weight is the crucial parameter. Thereby historical input data is unfavorable because the probability that a disaster occurs a second time in the same dimension is quite low.

Because a) seems to be the more crucial factor for relief supply chains, a third computation was made to estimate the optimal location according to operating time which is equal to the target of minimizing the total distance for all disasters, provided that the transport capacity is unrestricted. This was realized by setting the transport weights for every disaster equal to 1. A satisfying accuracy was reached after the 7th iteration. This time the optimal facility location has the geo-coordinates (50.2006°; 74.6191°) and is in Kazakhstan. By contemplating this position on a landscape the impression received that Kazakhstan could be the balance point of the total land of the world and this would be a time optimum for reaching every corner of the earth’s land. Figure 2 shows a coordinate system on a landscape to illustrate the positions of the large disasters and the computed location of a centralized single quick response depot for Humanitarian Logistics.
COMPARISON OF HUMANITARIAN RESPONSE DEPOT SETUP

To get an impression about the quality of a centralized single quick response depot, the computed solution was compared to the depot setup of the two big relief organizations IFRC and WFP according to overall distances and overall transport performances. The IFRC maintain three locations for storing relief supplies and the WFP five locations. These depots provide logistic service like delivery of humanitarian relief items within 24 hours at latest 48 hours to any location around the world by a disaster event as well as procurement, customs declaration services and storage of commodities. The most stored commodities in this network are medical kits, shelter items, IT equipment and mobile office simultaneous serve this as the specific relief items which needed in the first time in a disaster event. For computing the overall distance and the corresponding transport performance for these two setups, it is assumed that the delivery of relief items is always executed from the depot nearest to the disaster location. This was computed with equation (2). The results are shown in table 4. As the results show that suggestion of a single centralized depot causes the highest transport effort to supply the affected people with relief items. But it has to be considered that the maintenance of stocks causes costs and the more stocks have to be maintained the expensive are the fixed costs of the relief chain. The central idea is that the overall costs of maintenance and transportation are lower if only one centralized quick response depot would be operated than three or five depots.

Table 4: Comparism of humanitarian response depot setups

<table>
<thead>
<tr>
<th>Organization</th>
<th>Number of depot</th>
<th>Overall distance [km]</th>
<th>Overall transport performance [tkm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>58.329</td>
<td>29.611,766.349</td>
</tr>
<tr>
<td>IFRC</td>
<td>3</td>
<td>21.845</td>
<td>19.584,886.662</td>
</tr>
<tr>
<td>WFP</td>
<td>5</td>
<td>17.946</td>
<td>18.690,466.711</td>
</tr>
</tbody>
</table>

Another supposition is that the quick delivery of the relief supplies would be faster if it is organized from one depot because less coordination effort is necessary and this reduction of reaction time allows a more efficient planning of the relief distribution network to secure permanent deliveries to the disaster location over a longer period of time.

CONCLUSIONS AND FUTURE DEVELOPMENT

Humanitarian Logistics is an important sector which request for tools to support actions and decisions in this field. After the extensive literature review the idea of an establishment of one central response depot in the world has not been addressed in literature until this time. In this research paper a mathematical model was constructed to present the location of a central response depot where many first supplies have to be stored as a pre-positioned stock. It can also be seen as a concept of preparedness. The authors suggest that with a central response depot the delivery time of the first supplies needed would be reduced, the distance to every country in the world would be minimized and an effective and an efficient logistic organization could be established towards the affected people in case of disaster. This work proposes a new approach for the future which is based upon preventive action, cost, time, reliability and security. Furthermore the idea of an implementation of one HUB center is also possible and is not yet established in the sense of Humanitarian Logistics.

Then the first main problem in Humanitarian Logistics is also the coordination of relief items at the local distribution center in a disaster location. Some stakeholders send their relief items uncoordinated to the disaster location and overload the available place which can be small cause of destroyed areas by natural or man-made disasters. The second main problem in Humanitarian Logistics is that the stakeholders do not cooperate as the ideal meaning of supply chain management; these problems could be reduced and solved by a deployment of one global response depot as a HUB center in Humanitarian Logistics. For example if shipment evaluation, tracking and tracing also an overview about the incoming and outgoing shipments are existing, an increase of the performance measurement is possible by operation of one HUB center. This model is specially created for Humanitarian Logistics and has been used for a data set of the greatest disaster which occurred 2001 to 2010 to illustrate a promising result. Future research could better use forecast data to present an even more convincing result. Possible is also to find a central country on the earth based upon geo-coordinates. Hereby is to verify the infrastructure, the traffic system and the procurement opportunities to cover the preparedness of a disaster response in effective and efficient way. Future research also needs to develop of a hub and spoke system which is suitable to humanitarian relief operations and where all humanitarian organizations could participate in an efficient logistics network and could
therefore deliver the supplies within 48 hours to the most affected people in disaster locations throughout the world.

REFERENCES
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BIOGRAPHY
CHRISTOF KANDEL studied industrial engineering at University Duisburg-Essen. During his study he worked at WOITH paper in Krefeld in the department of project management and afterwards at SIEMENS Energy in Duisburg in the department “procurement & logistics”. After his studies he began to work at FOM ild – Institute for Logistics and Service Management in December 2010 as research assistant.
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MATTHIAS KLUMPP is professor for business administration, especially logistics at FOM University of Applied Sciences and scientific director of FOM ild – Institute for Logistics and Service Management.