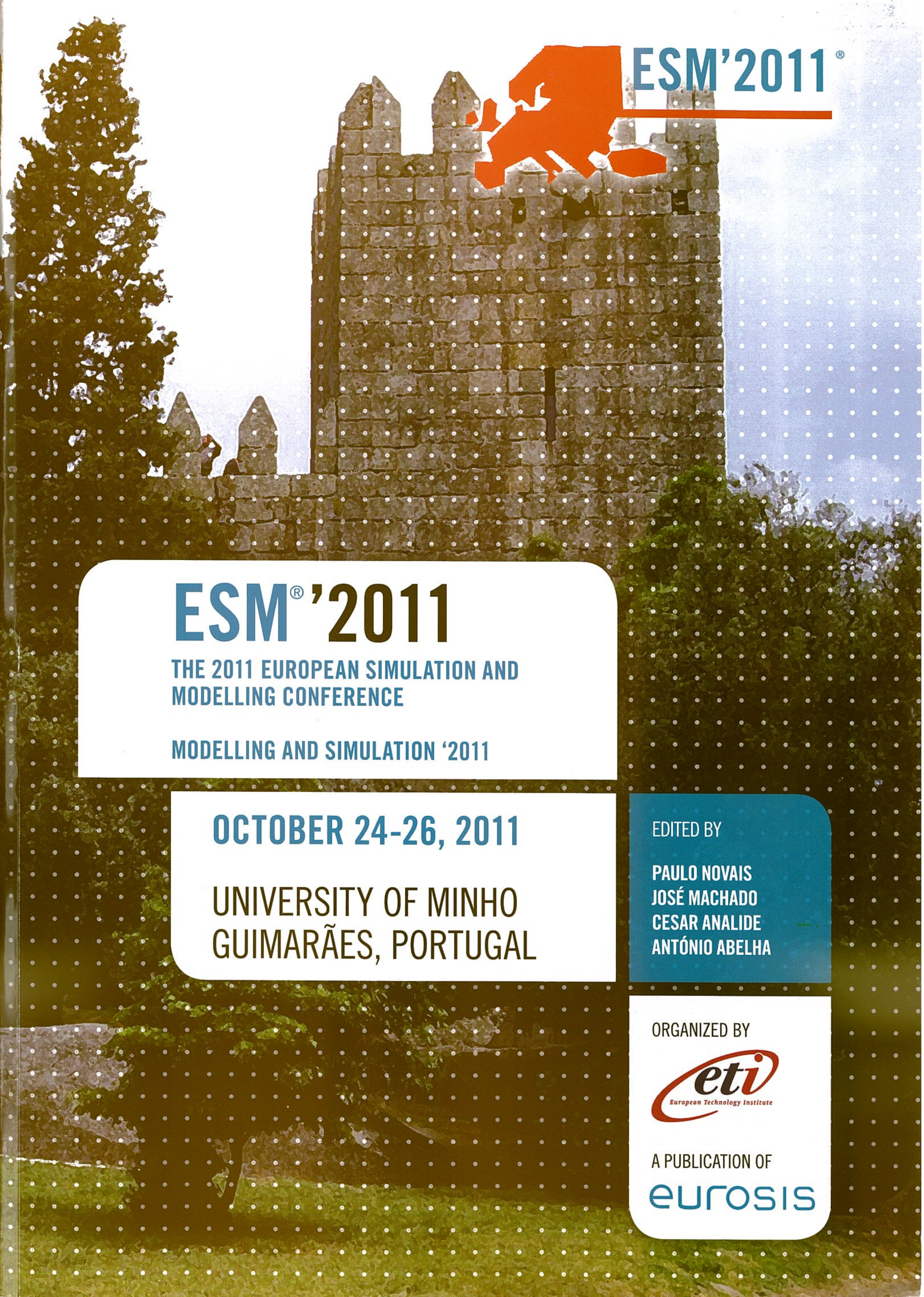

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HUMANITARIAN LOGISTICS DEPOT LOCATION MODEL

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Humanitarian Logistics, Depot Location Model, Network Storage, Response Depot Simulation

ABSTRACT

Lack of coordination and collaboration among participants of humanitarian relief chains, high costs in the area of Humanitarian Logistics and long transit times of goods build this research paper on the idea that the response depot location should be improved to reach the required delivery time of 24/48 hours by producing lower transport and logistics cost in case of a disaster in the world. With this in mind this research article describes the humanitarian relief chain, the depot locations of two global players such as International Federation of the Red Cross and the UN World Food Program in a disaster relief. Furthermore the typical location problem in logistics will be solved especially for one single global depot location in Humanitarian Logistics by developing and using a mathematical location planning model. Finally to outline the research strategic locations of depots for more effective humanitarian supply chains will be compared. The focus is to develop a mathematical model based on the fact that there are not many mathematical solution programs for strategic and tactical decisions in the area of Humanitarian Logistics. According to a literature review in the period of 2005 till 2010 in scientific and academic publications in journals and conferences proceedings only 7 publications focused on research methodology such as mathematic 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 exciting 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.

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 which were sourced from the science and management journal databases such as Emerald, Business Source Premier and Science Direct only focused on 7 publications with research methodology such as mathematic models. The majority academic research on this topic was published in 2005 after the Indian Ocean Tsunami in 2004 (Kovács and Tatham 2009). Following scientific and academic papers were published dealing with the topic of Humanitarian Logistics: 2004 Beamon about the comparison of humanitarian relief chain and commercial supply chains, 2005 Pettit and Beresford; 2007 Tovia; 2009 Maon et al. presented the Humanitarian Logistics model, 2006 Beamon and Kotleba describe the inventory management in humanitarian relief, 2008 Beamon and Balcik showed an example for performance measurement, 2009 Kovács and Spens; 2010 Chandes and Pache gave an overview about the challenges in Humanitarian Logistics, 2008 Balcik 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 Balcik et al. and 2010 Taham and Kovács 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 Balcik and Beamon in 2008 about facility location planning. The paper of Balcik 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 1: Classification of disasters

Biological	Geophysical	Hydrological	Meteorological	Climatological
-Epidemic: Viral, Bacterial, Parasitic, Fungal, Prion Infections Disease **-Insect Infestation** **-Animal Stampede**	**-Earthquake** **-Volcano** **-Mass Movement (Dry):** Rockfall, Landslide, Avalanche, Subsidence	**-Flood:** General Flood Flash Flood Storm Surge/Coastal Flood **-Mass Movement (Wet):** Rockfall, Landslide, Avalanche, Subsidence	**-Storm:** Tropical Cyclone, Extra Tropical Cyclone, Local Storm	**-Extreme Temperature:** Heat Wave, Cold Wave, Extreme Winter Condition **-Drought** **-Wildfire:** Forest Fire Land Fire

This argues for the range activities of Humanitarian Logistics and their efficient organization. Then Humanitarian Logistics “required to procure, store and distribute supplies for the assistance of beneficiaries” in case of a disaster (Howden 2009). Logistics in the humanitarian sense strives to prevent and minimize starvation, disease and death as an effect of natural, technological or man-made disasters by effectively providing basic needs such as food, water, shelter and medical care to all victims (Blecken 2010). Humanitarian Logistics is defined as the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people” (Thomas and Kopczak 2005).

The stakeholders of Humanitarian Logistics are beneficiaries, donors, the media, host government, disaster response operations, regional organizations an in-country operations (Thomas 2003).

An efficient Humanitarian Logistics commits a coordination between the stakeholders, optimization of response depots, distribution network, performance measurement and short delivery times by including following functions such as (Howden 2009):

- warehousing (storage and handling)
- transportation (planes, cars, trucks, rail, ship)
- security, fleet management
- procurement (material, food, medical, water, sanitation, sources of energy)
- asset management, build management
- communication and information technology (radio, internet, phones)

in an environment with limited or no existing of infrastructure and communication (Rickard 2006).

This complex logistic structure although resembles to commercial logistic but they are many weaknesses in (Fuessel et al. 2006):

- coordination among the stakeholder
- procurement process which is fragmented
- non-transparent contracts and conditions
- out of stock situation and commodity shortages
- infrequent orders
- overstretched storage and delivery routes

The above mentioned Humanitarian Logistics challenges argue for the main emphasis addressed in this paper. Humanitarian Logistics performance can be increased by the optimum location of humanitarian response depot in the whole world, then the efficient handling of fleet management and minimize of transport distance mean minimize of transport costs. All these aspects maximize the output such as food, medical, shelter, water sanitation deliveries and all the needs of beneficiaries in a short transit time and the out of stock situation will be decreased. To create a mathematical model for the optimum of the location of humanitarian response depot following assumptions for simplification has to be made in order to achieve a useful result (Table 2):

I) The needed data was adapted from CRED database: 11 large disaster events over the period 2000-2010 were used as input-data for the mathematical model. CRED determined following criteria in their database

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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

Kit	Weight [kg]	Quantity of people for each kit	Weight/ Person [kg]
Domestic	24	5	4.800
Sanitation	329	5	65.800
Health	998	30000	0.033
Tent	55	5	11.000
Shelter	20	5	4.000
Water	7000	10000	0.700
		sum [kg]	86.333
		sum [tons]	0.0863

Table 2: Database for a location model and calculation

i	popular name	main countries affected	date	type of hazard	main city affected	latitude ρ			longitude λ			people	transport
						[°]	[min]	[dez.]	[°]	[min]	[dez.]	affected	weight [t]
1	Haiti earthquake	Haiti	2010-01-12	Earthquake	Port-au-Prince	18	32	18.53	-72	-20	-72.33	3,400,000	293,533
2	Sichuan Earthquake	China	2008-05-12	Earthquake	Chengdu	30	40	30.67	104	4	104.07	45,976,596	3,969,310
3	Cyclon Nargis	Myanmar	2008-05-02	Tropical cyclone	Yangon	16	47	16.78	96	9	96.15	2,420,000	208,927
4	Java Earthquake	Indonesia	2006-05-27	Earthquake	Yogyakarta	-7	-48	-7.80	110	22	110.37	3,177,923	274,360
5	Kashmir Earthquake	Pakistan	2005-10-08	Earthquake	Muzaffarabad	31	21	31.35	73	28	73.47	5,128,000	442,717
6	Hurricane Katrina	United States	2005-08-29	Tropical cyclone	New Orleans	29	57	29.95	-90	-5	-90.08	500,000	43,167
7	Mumbai Floods	India	2005-07-26	Flood	Mumbai	18	58	18.97	72	50	72.83	20,000,055	1,726,670
8	South Asian Tsunami	Indonesia, etc.	2005-12-24	Tsunami	Banda Aceh	5	33	5.55	95	19	95.32	2,321,700	200,440
9	Bam Earthquake	Iran	2005-12-23	Earthquake	Bam	29	6	29.10	58	21	58.35	267,628	23,105
10	Dresden Floods	Germany	2005-08-11	Flood	Dresden	51	3	51.05	13	44	13.73	330,108	28,499
11	Gujurat Earthquake	India	2001-01-26	Earthquake	Bhuj	23	15	23.25	69	40	69.67	6,321,812	545,783

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).

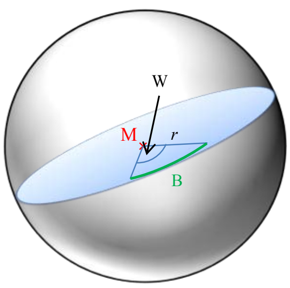

Figure 1: Distance calculation methodology

Equation (1) shows the relation between the apex angle W in radian, the radius of the ball and the geo-coordinates of the points {ρ, λ; ρ_i, λ_i} defining W:

$$B = r\cos^{-1}(\cos\varphi\cos\varphi_i\cos(\lambda-\lambda_i)+\sin\varphi\sin\varphi_i) \qquad (1)$$

This distance measurement methodology has to be integrated in Weber’s facility location problem instead of the Euclidean distance measurement l_2.

Therefore the following parameters have to be set:

- average earth radius is r = 6,371 km.
- set of customers as disasters with geo-coordinates (ρ_i, λ_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 (ρ, λ) as target coordinates of the centralized quick response depot.

$$\min\sum_{i=1}^{n} b_i\cos^{-1}(\cos\varphi\cos\varphi_i\cos(\lambda-\lambda_i)+\sin\varphi\sin\varphi_i)\cdot 6371 \qquad (2)$$

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 ρ nor for λ, an analytical optimum cannot be estimated. Because for solving the Euclidean single facility

location problem the same problem occurs, Miehle developed an iterative method to estimate the optimal location. By using this method only few iteration steps suffice for receiving a satisfying accuracy (Miehle 1958). This iterative method for the location problem in plane has to be transferred to this facility location problem on the surface of a ball as follows:
First the partial derivatives of (2) with respect to ρ and λ have to be estimated:

$$\frac{dF}{d\varphi} := \sum_{i=1}^{n} -\frac{6371 b_i (\sin\varphi_i \cos\varphi - \cos\varphi_i \sin\varphi \cos(\lambda-\lambda_i))}{\sqrt{1-(\cos\varphi_i \cos\varphi \cos(\lambda-\lambda_i) + \sin\varphi \sin\varphi_i)}} = 0 \quad (3)$$

$$\frac{dF}{d\lambda} := \sum_{i=1}^{n} -\frac{6371 b_i \cos\varphi \cos\varphi_i \sin(\lambda-\lambda_i)}{\sqrt{1-(\cos\varphi_i \cos\varphi \cos(\lambda-\lambda_i) + \sin\varphi \sin\varphi_i)}} = 0 \quad (4)$$

Then (3) and (4) have to be solved for ρ and for λ 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 ρ^0 and λ^0 and the results ρ^1 and λ^1 has to be set as ρ^0 and λ^0 in the next iteration step as long as the difference ε between ρ^0 and ρ^1 as well as λ^0 and λ^1 is smaller than a pre-defined boundary.

$$\varphi^1 = \cos^{-1} \frac{\sum_{i=1}^{n}(-6371 b_i \cos\varphi_i \sin\varphi^0 \cos(\lambda^0-\lambda_i) / \sqrt{1-(\cos\varphi_i \cos\varphi^0 \cos(\lambda^0-\lambda_i)+\sin\varphi^0 \sin\varphi_i)}\,)}{\sum_{i=1}^{n}(-6371 b_i \sin\varphi^0 / \sqrt{1-(\cos\varphi_i \cos\varphi^0 \cos(\lambda^0-\lambda_i)+\sin\varphi^0 \sin\varphi_i)}\,)} \quad (5)$$

$$\lambda^1 = \cos^{-1} \frac{\sum_{i=1}^{n}(-6371 b_i \cos\varphi^0 \cos\varphi_i \sin\lambda^0 \cos\lambda_i / \sqrt{1-(\cos\varphi_i \cos\varphi^0 \cos(\lambda^0-\lambda_i)+\sin\varphi^0 \sin\varphi_i)}\,)}{\sum_{i=1}^{n}(-6371 b_i \cos\varphi^0 \cos\varphi_i \sin\lambda_i / \sqrt{1-(\cos\varphi_i \cos\varphi^0 \cos(\lambda^0-\lambda_i)+\sin\varphi^0 \sin\varphi_i)}\,)} \quad (6)$$

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 $\varepsilon < 0.1$ and the start coordinates (-1.28333°; 36.816667°) are in Nairobi, Kenya. The boundary ε 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 with Kashmir Earthquake in Pakistan and Bam and Gujurat Earthquake in India the three largest disasters according to the transport weight are in the immediate vicinity of the estimated location.
This reasons that the transport weight impacts the target function maybe too strong proportional to the distance for estimating the optimal location of a centralized single quick response depot for future. By reason of this finding it has to be questioned which parameter is more important for a humanitarian relief chain:

a) Operating time to reach the disaster location as soon as possible from the depot. Therefore the distance is the main parameter and this can be computed comparatively reliable 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).
b) Transport 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.

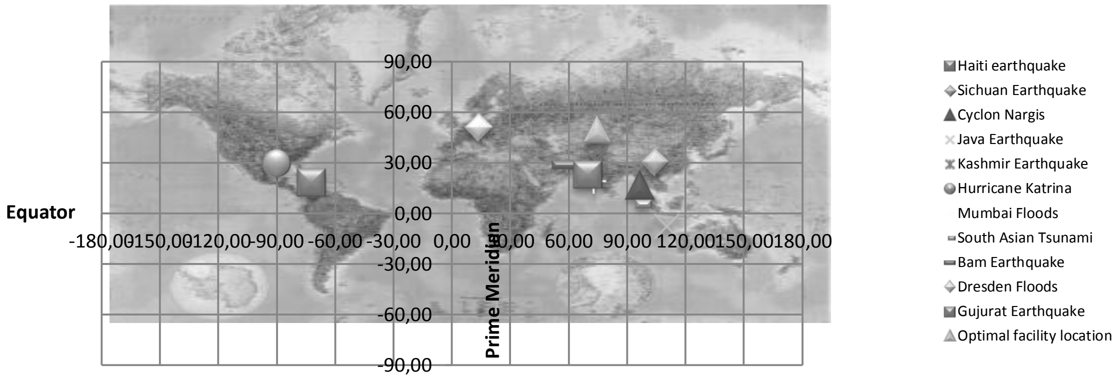

Figure 2: Location of large disaster events and optimal facility location of quick response depot

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 hast 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

Organization	Number of depot	Overall distance [km]	Overall transport performance [tkm]
Model	1	58.320	29.611.766.349
IFRC	3	21.845	19.584.886.662
WFP	5	17.946	18.690.466.711

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.

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