Using transportation problem in humanitarian supply chain to prepositioned facility locations: a case study in the Democratic Republic of the Congo

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Abstract Over the last two decades, the Democratic Republic of Congo (DRC) has been plague by conflicts that has caused the lives of millions of Congolese in the eastern parts of the country while displacing many more. These multifaceted man-made conflicts have contributed to the crumbling of the regional infrastructures and transportation system, to insecurity, poverty and many more. Despite the region huge human, minerals, forestry and energy potential for development, the DRC authorities and international organizations operating in the region have largely failed to ensure farmers, miners, scholars of the Eastern Congo safety during their day to day routine. It is for such reason, humanitarian reliefs are needed to supplement any shortfalls in term of foods, medicines, shelters and others. This research aimed at optimizing prepositioned relief supply to the region. This study intends first to identify potential prepositioned relief locations in the three most conflicts heated provinces in the Eastern Congo (Ituri, South Kivu and North Kivu). Then, the study uses transportation problem in minimizing the total costs and the total time of distributing goods from supply points (sources) to a number of demand points (destinations). The model outcome reveals that by incorporating all transportation modes into the operation, humanitarian organizations are more flexible against infrastructures, health or security challenges that often ravage Eastern Congo.

Keywords Humanitarian logistics · Disaster relief operations · Democratic Republic of Congo · Lean manufacturing · Prepositioned facility locations

1 Introduction

Disaster relief supply chain is the movement of personnel and humanitarian supplies to affected zones in order to alleviate the suffering of the vulnerable (Strawderman and Eksioğlu 2009).

As documented by several accredited researches, the impacts of natural and man-made disasters in the Southern African Development Community (SADC) region have been in the rise, with the latest prediction pointing towards more events in the future. However, Starr and Van Wassenhove (2014) note at a source an apparent lack of organized plan to reach victims and especially in the aftermath of a disaster. Among the SADC country most affected by natural and man-made disasters is the Democratic republic of Congo (DRC).

This resource rich country in the central Africa, a country in the size of a continent is the access point between the East and the West of the African continent. Unfortunately, the country has been a subject of never-ending conflicts that have caused the loss of many lives while subsequently straining humanitarian organizations efforts (Kembro 2012). Table 1 has revealed that the Democratic Republic of Congo has suffered over two hundred natural and man-made disasters, with nearly 6 million people being killed by man-made disasters only (WFP 2013) and 3 million more being displaced (WFP 2013). The conflicts in the DRC were inherited from the country independence in 1960. In the last 25 years

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Table 1 DR congo man-made and natural disaster values from OFDA CRED international disaster database value for all SADC countries between 1900 and 2016

Country	Natural disaster	Number of events	Killed	Total affected	Damage (US\$ 000)
DRC	Man-made	116	5,872,000	2,600,000	
	Natural	102	10,381	272,096	21,600
Total		218	5,882,381	2,872,096	21,600

however, the country has experienced a bloodier and more deadly arm conflicts in the Eastern side of the DRC, specifically in the North, South Kivu and the Ituri Province.

Looking into the proportion of Natural and Man-Made disasters in the SADC region, the Democratic Republic of Congo is the second country with the greatest number of both type disasters with 218 cases.

According to Oxfam (2014), the 6 million deaths toll, could be even higher according to other reputable bodies estimates, is largely attributed to the secondary effects of prolonged conflict, impacting the country, its inhabitants, its foods security, its health care infrastructures with as causes the contamination of drinking water as well as the resurface of poor sanitation practices that has led to epidemics such as Cholera, measles or even Ebola. Other notable consequences include the inaccessibility of relief organizations to disaster-prone areas in the eastern Congo due to poor infrastructures (Mpita et al. 2016), leading to relief supplies scarcities in the affected region (WFP 2012).

DRC supply chain and logistics are viewed as a major challenge. To face all those challenges, a new style of preparedness is needed by humanitarian organizations operating in DRC in order to respond timely to the predictable demands caused by on-going conflicts. This research aim is the optimization of prepositioned relief supply to the region. To achieve the above aim, the following objectives will be developed:

1. The identification of potential prepositioned relief locations targeting the three most conflicts heated provinces in the Eastern Congo (Ituri, South Kivu and North Kivu).
2. Then, the development of a transportation model that minimizes the humanitarian supply chain cost and time.

2 Literature reviews

2.1 Importance of humanitarian logistics

This study focuses on the development of humanitarian logistics operations in one of the most vulnerable regions in

the African continent. This operation assists minimize the human suffering and death caused by natural and man-made disasters (Balcik and Beamon 2008). Strawderman and Eksioglu (2009) defined Humanitarian logistics as the process of planning, implementing and controlling the efficiency, the cost effectiveness of goods flow and storage as well as materials and related information from their origins to their consumptions.

Strawderman and Eksioglu (2009) further states that although humanitarian logistics assure that the planning is done effectively, the movements of personnel and supplies are completed by disaster relief supply chains, which directly affect the performance of humanitarian aid. Disaster relief chains is defined by Thomas (2004) as the systems and processes involved in mobilizing people, resources, skills and knowledge to help vulnerable people affected by natural disasters and complex emergencies. The function incorporates a range of activities such as preparedness, planning, procurement, transport, warehousing, tracking and tracing, customs and clearance (Thomas 2004).

Tatham and Houghton (2011) note an increase in recent years of the interest by the international academic community on the challenges faced worldwide in term of humanitarian logistics (Kovács and Spens 2009), especially researches and publications that focus on real lives case scenarios. zooming into the increase globally in term of natural and man-made disasters as well as to the current covid-19 challenge that have ravages the world and its economy, the use of supply chain management is able to assist communities' pre- or post-disaster recovery in different means (Tatham and Houghton 2011). Among the means, Supply chain is able to resolve issues related to "the lack of proper planning, communication and coordination challenges, the inaccessibility of regions and cities affected by conflicts, the unpredictable nature of new conflicts, and security issues caused by the conflict" (RDC Humanitaire 2020; Oxfam International 2014; Kembro 2012). Both humanitarian logistics and supply chain techniques deserve to work hand in hand in order to optimize timely relief supply in the region.

Furthermore, limited reviewed papers have explicitly targeted the regional transportation problems and ways to

optimize their efficiency (quick action) and effectiveness (low-cost) during a humanitarian operation. Transportation problem either maximize or minimize the objective function given the set of alternatives. Alternatives (feasible or constraint region) is essential in order to minimize the transportation cost and time in SADC region (Figs. 1, 2).

2.2 Case study of the (DR Congo)

For the past 20 years, the eastern part of Congo (North, South Kivu and Ituri) has encountered, according to BBC magazine report, the bloodiest conflict in the world since World War two (WW2). These conflicts have led to loss of lives, civilian displacements as well as the regional economic mayhems. This country, potentially rich with the United States Geological Survey estimated in 2009 that the Democratic Republic of the Congo (DRC) untapped mineral deposits to \$24 trillion, including the world's largest reserves of Coltan (essential element for phone manufacturer) and significant quantities of the world's cobalt (essential element for electric car manufacturers). Estimation shows that the DRC possesses 1 million tons of lithium resources. In addition to Eastern Congo large Coltan, Gold, Diamond, thin, lithium or natural gas deposit, it has in continuity with other provinces the world largest forest (equator forest), only after amazon, and has a largely untapped farmlands with the arable land potential to feed one billion people, nearly the rest of Africa (World Bank 2020). Yet, according to the same source, disputes over these resources drive the conflicts, and rebel groups seek to control them to fund their own campaigns (Counsel of Foreign Relations 2020). Furthermore, the eastern region of DRC has been grappling with an Ebola outbreak especially in the North Kivu and Ituri provinces since August 2018. According to the World Bank report (2020), the instability and insecurity that have faced the region has long hampered the country's Ebola response. As of June 13, 2019, 2084 cases (1990 confirmed and 94 probable cases) had been identified by the World Health Organization. Of the number of cases, 1405 have died among which women (57%) and children (29%). Figure 3 shows the areas

Fig. 1 DRC man-made and natural number killed and total affected

Fig. 2 Total SADC man-made and natural disaster proportion

affected by Ebola in the Eastern part of Congo. While Table 2 shows the type of disasters that have affected each province in the region.

For Man-made disasters, conflicts have affected all three provinces in the Eastern Congo. With DRC central government inability to resolve ethnics and regional differences, top to that the systematic collapse of the state footprint into the regional key infrastructures and mining facilities, the Counsel of Foreign Affairs (2019) believes that many in the eastern Congo felt abandoned and left to deal with all those conflicts for themselves, both economically and militarily. The resulting proliferation of militias has become deeply intertwined with local economies (Counsel of Foreign Affairs 2019). These conflicts led at some point several key Coltan, gold and other important mines falling under the control of rebel groups. Figure 4 has listed the key rebel groups fueling conflicts in the Eastern Congo.

Informal, or “artisanal,” mining, as shown in Table 2 constitutes as much as a one-fifth of the country's economic output and offering employment to nearly two million of people in eastern Congo according to the United Nations estimates (2018), also contributing up to 22% of the Congo GDP (International Monetary Fund 2017). Artisanal mining trade is also a worthy catalyst for conflicts as it serves as source of income for arm rebel groups and corrupt government officials alike, as well as for illegal

Fig. 3 Areas affected threaten by Ebola Epidemic in the Eastern Congo (OCHA RDC 2019)

Table 2 Type of natural and man-disaster affecting the three provinces in the Eastern Congo (EM-DAT 2016; World Vision 2018)

Study provinces	Type of disaster	
	Natural disaster	Man-made disaster
<i>DRC</i>		
South Kivu province	Gas flaring, floods, landslides, epidemics and pandemics	Artisanal and small-scale mining, arms conflicts
North Kivu province	Gas flaring, deforestation, volcanoes, epidemics and pandemics	Artisanal and small-scale mining, arms conflicts
Ituri province	Landslides, floods, deforestation, epidemics and pandemics	Artisanal and small-scale mining, arms conflicts

traders operating from neighboring countries directly or through local armed allies (Counsel of Foreign Relations 2020).

Many humanitarian organizations are actively operating in the Eastern region of the DR Congo, providing people with much needed humanitarian reliefs. These abilities to respond timeously have however been hampered by the risk of being caught in the crossfire as a result of the unpredictable nature of those conflicts. Other challenges faced by relief organizations include the absence of proper planning (considering the natural and man-made disasters affecting the region), lack of communication and co-ordination challenges and the inaccessibility of regions and villages affected (Mpita et al. 2016, RDC Humanitaire 2020; Oxfam International 2014; Kembro 2012).

2.3 Pre-positioning relief supply in DRC

For Hale and Moberg (2005), the storage of emergency supplies, equipment, and vital documents that is needed in times of crisis are a critical component of disaster

management planning in supply chains. To achieve that, Turnquist and Rowls (2009) believe that preparing the region is by prepositioning supplies at strategic locations to ensure that reliefs are safe and available when needed. With the all Eastern side of the DRC being exposed to risk of potential new disasters, it worth developing new pre-positioned relief supplies in those three affected provinces, taking into account the accessibility to the warehouses, the security of personnel's managing those warehouses and the goods, the locations of those facilities ensuring that they are as close as possible and as accessible as possible to the victims. Other key element to make sure of is that the warehouses are holding adequate quantity.

2.4 Humanitarian logistics and facility location problem in humanitarian context

Disaster occurs unexpectedly, which result to a sudden higher demand for supplies but only in a short response time (Mpita et al. 2016). To address these crisis, Tomasini and Van Wassenhove (2009) suggested propositioning the

Fig. 4 Rebel groups operating in the Eastern Congo

right kind of supplies, in the right quantities at the right place and time for future need. Prepositioning location facility has therefore emerged in the recent years as one of the most effective tools in humanitarian disaster planning. For the preposition relief supplies efforts to be successful, Balcik and Beamon (2008) argue on the need for the location planning for warehouses as a critical step in the disaster management process. Kunz et al. (2013) further emphasize on the key role disaster preparedness plays in reducing the impact of disasters worldwide, and prepositioning is a preparedness method used especially by countries with natural or man-made disasters history. In the last decades, a lot of research has looked in prepositioning in the context of disaster relief or emergency response. Tomasini and Van Wassenhove (2009) believe that applying prepositioning method lowers procurement costs and increases the speed of relief supplies to disaster areas by allocating the potentially needed goods closer to demands points. Most of reviewed literatures dealing with the prepositioning of disaster relief are more focused on a strategic decision level such decision related to finding the best locations for facilities as well as determining the quantity of stock supplies (Root et al. 2012). For facility locations planning, Caunhye et al. (2011) and many other authors used Mixed-Integer programmes with binary location variables for locating potential facilities able to

preposition relief supplies. Duran et al. (2011) for instance used a mixed-integer programming formulation to calculate the optimal locations and stocking relief supplies. Duran et al. (2011) model minimizes the average response time for transporting the relief supplies from selected prepositioned warehouses or global supplies to regional demand locations. And based on the disaster scenarios faced, the best decision will be selected.

Other key contributors to the topic such as Campbell and Jones (2011) and Balcik and Beamon (2008) used mathematical models to quantify and locate potential distribution center (DC) to be part of emergency facilities network, also inventory management at the established facilities. Kim et al. (2011) introduced a quantitative approach to multi-objectives prepositioning by maximizing the total expected relief demand of a potential vulnerable disaster areas. This approach assists distribution centers through four objectives: (1) maximum response time limit, (2) budget availability, (3) multiple item types, and (4) capacity restrictions. Furthermore, Van Wyk et al. (2013) presented a multi-objective approach to prepositioning of the relief supplies in Somalia. To solve the model, these authors above used pre-emptive optimization model which improves one objective function at a time without compromising the others. This approach has been found useful for multiple conflicting objectives.

Nahleh et al. (2013) solved another multi-objective facility location problem in emergency logistics by integrating business ‘best practices’ such as just-in-time, addressing therefore facility location problem in terms of material flow. Nahleh et al. (2013) findings also include an escalation of orders from local DC to regional, continental as far as the main warehouses, to replenish the initial relief items that were distributed to affected area. According to Timperio et al. (2017), this model by Nahleh et al. (2013) looks at facility location problem in emergency logistics more from a global perspective, rather than last mile (in country) logistics. In Nahleh et al. (2013) model, the country affected by a disaster requests support from the nearest regional prepositioned DC which, while assisting beneficiaries, will place relief items restock orders to continent warehouse. The continental warehouse, following the similar pattern, will place an order to the main warehouses (Nahleh et al. 2013).

Multi-criteria decision making (MCDM) is both a quantitative and qualitative way of optimizing the pre-positioning locations facility. The MCDM was first represented in the perspective of facility location problem by designing a framework and ranking them in terms of importance by Roh et al. (2013) contrasting Hale and Moberg (2005) approach that focused on the pre-positioning of strategic stockpiles from the perspective of cost efficiency. Roh et al. (2013) proposes a secure facility selection process, balancing the “operational effectiveness and cost efficiency through the identification of the minimum number and possible locations of offsite storage facilities” (Hale and Moberg 2005).

Degener et al. (2013) uses of multi-criteria decision making in a small-scale to a real-life scenario in Bangladesh helped bring more transparency in results. Recently, MCDM was employed by Timperio et al. (2017) to provide a decision support framework for facility locations identification with the purpose of addressing network design in Indonesia disaster relief supply chains. Among the researches listed and described above, none of them captures the technicalities of a real-life case as such covered by Timperio et al. (2017), particularly from the perspective of multi-criteria decision making. Most literature reviews that deal with facility location problem through optimization techniques with the support of quantitative data. Timperio et al. (2017) approach, used in this research, is an interdisciplinary approach that integrated both quantitative and qualitative evidence, and providing a full-bodied and adjustable methodology when replicated in other contexts. The decision support used in this study integrates quantitative and qualitative data and applied in linear programming model.

3 Research methodology

In the study methodology, we describe the key logistical challenges affecting facility location and transportation decisions. Then this section will define the facility location problem, and present the model formulation.

3.1 Model description

Relief delivery system involves a large number of players and stakeholders (beneficiaries, host governments, local and international relief organizations, donors, etc.) and operates in highly unpredictable, dynamic and disordered environments (Balcik and Beamon 2008). Each and every stakeholder ensures that the relief operations are done quickly and effectively. Successful disaster response activities during or in the aftermath of a conflict take into account a wide range of factors among which uncertainties, variability in the relief types, the relief sources or even the warehouses to store the reliefs just acquired. Unlike it is accustomed in a commercial supply chains where logistic operations are more consistent therefore planned in advance of demand, most logistical decisions in the humanitarian relief chain however are made within shorter time frames (Balcik and Beamon 2008). To deal with high-performance disaster response, long-term supply chain planning is required for facility location as well as the stock pre-positioning decisions. Disaster happens suddenly, and once it has, demands for large amounts of goods of different variety of supplies suddenly occurs. Beamon (2004) identified in Fig. 5 four main phases of disaster relief representing the flow of resources to the affected areas: (1) assessment: critical process because it demonstrates the ability of a relief organization to identify what minimal resources are required, then (2) deployment mobilizes the resources required to meet the needs, (3) sustainment: operations are continued for a period of time, and (4) reconfiguration: operations are reduced, then brought to an end.

Each phase listed in Fig. 5 varies depending on the disaster characteristics and the region level of preparedness for disaster. However, the speed is essential at every relief operations phase in order for them to live up to their expectation of saving lives.

3.2 Data gathering

Besides literatures review, the study has utilized various agencies and departments active in climate variability monitoring and response. Although articles and past reviewed papers served the research a great deal; Governmental, non-governmental and intergovernmental

Fig. 5 Relief mission life cycle. Source: Beamon (2004)

organizations assisted in identifying the history of conflicts in the Ituri, North and South Kivu. The following agency databases were utilized for this research: EM-DAT, United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), DRC Emergency Agency, RDC Humanitaire, Relief Web International, World Bank RDC, and World Health Organization, Counsel of Foreign Relations, CARE, OXFAM, USAID, FAO/WFP, NOAA, DRC HF, Public Health Emergency of International Concern (PHEIC) and other collaborating institutions.

3.2.1 Identified conflict areas and storage facility locations

The potential conflict areas listed in the Table 3 were collected from various sources operating in the region. The table also identified the Total number of conflicts in those areas and the probability of conflicts in cities in North Kivu, South Kivu and Ituri. Table 3 also shows that even areas with small population size were not spared from conflicts. The facility locations should ideally be located into conflicts areas with relatively higher population size, but with lower probability of conflicts. The higher population size cities in DRC often possess more structured administrative systems, relatively fair infrastructures and

Table 3 Probability of conflict in identified conflict areas

Provinces	Conflicts area	Total number of conflicts	Probability of conflict
North Kivu	Masisi	31	0.136
	Beni	30	0.132
	Lubero	23	0.101
	Rutshuru	16	0.070
	Walikale	16	0.070
	Butembo	10	0.044
	Goma	7	0.031
South Kivu	Uvira	15	0.075
	Shabunda	15	0.066
	Fizi	10	0.053
	Kalehe	9	0.039
	Mwenga	7	0.031
	Kabare	3	0.026
	Walungu	1	0.018
Ituri	Djugu	10	0.044
	Irumu	6	0.026
	Mahagi	4	0.018
	Mambasa	3	0.013
	Aru	2	0.009

transportation systems, deployed army and police units ready to defend the city against any attack. Also, to be added are hospitals, schools, churches, with all those offering humanitarian personnel viable option for facility locations. The lower probability of conflicts rate is equally important because it limits the impending risks on humanitarian personnel and reliefs. Table 3 summarizes the resulting list of potential storage locations.

As explained, the candidate locations for distribution centers as shown in Table 3 are the region with relatively higher population size while lower probability of conflicts from each of the three provinces. The locations of the 7 candidate sites for distributions centers in North Kivu, 8 candidate sites for distributions centers in South Kivu and 5 candidate sites for distributions centers in Ituri province. According to Table 4, Goma and Butembo are respectively the most populated cities with the best probability of conflict per population size in the North Kivu province. Bukavu and Mwenga are respectively the most populated cities with the best probability of conflict per population size in the South Kivu province. Mambasa and Bunia are respectively the most populated cities with the best probability of conflict per population size in the South Kivu province.

3.2.2 Transportation and response times

The Congolese government, the regional authorities and their partners use the capital cities of each province as the main distribution center (Bunia for ituri, Goma for North Kivu and Bukavu for South Kivu). And from those towns and towns from neighboring provinces, the humanitarian reliefs are transported to distribution centers located at various territories by road, helicopters or planes. For instance, the WFP owns a fleet of 18 military trucks in the both Kivu region, each with the capacity of seven metric-tonnes (WFP 2012). The UN mission in the Congo (MONUSCO) offers a great deal of assistance with it fleets of MI-8 helicopters and cargo planes ready to intervene especially in case of poor road conditions or bridges damage. It is worth noting the risk of ambushes from anti-government forces that humanitarian personnel's and goods are faced with especially on the poorly maintained roads where the average speed is estimated at 40 km/h.

3.2.3 Areas stock pre-positioning

Previous researches such as Mpita et al (2016), Reliefweb or RDC Humanitaire (2020) have detailed the number of displaced and various other challenges and reliefs expectation are needed. Mpita et al. (2016) use those data in the

Table 4 Potential locations of facilities

Provinces	Conflicts area	Population size	Total number of conflicts	Probability of conflict per population size
North Kivu	Goma	2,000,000	7	0.000004
	Butembo	1,154,621	10	0.000009
	Rutshuru	250,000	16	0.000064
	Walikale	201,000	16	0.000080
	Beni	231,952	30	0.000129
	Lubero	57,356	23	0.000401
	Masisi	6502	31	0.004768
South Kivu	Bukavu	870,954	5	0.000006
	Mwenga	806,940	7	0.000009
	Walungu	85,000	1	0.000012
	Shabunda	923,000	15	0.000016
	Kalehe	462,465	9	0.000019
	Uvira	378,736	15	0.000040
	Kabare	37,034	3	0.000081
	Fizi	30,000	10	0.000333
Ituri	Mambasa	249,073	3	0.000012
	Irumu	366,126	6	0.000016
	Aru	94,267	2	0.000021
	Mahagi	67,954	4	0.000059
	Djugu	28,061	10	0.000356

development of a model that integrates potential facility locations, multiple relief items, response times, and capacity restrictions while maximizing the proportion of demand satisfied by the pre-positioned relief supplies. However, in order to successfully pre-positioned stocks in regions with the history of arm conflicts, key considerations need to be taken into accounts. Among them are: (1) identification of best facility locations in each district, (2) available infrastructures and road conditions to reach those facilities, and finally (3) ensuring that the Transportation time and cost from main DC (chief town) to the district DC is minimized.

To achieve this research, aim of stock pre-positioning, certain assumptions need to be raised:

- The choice of transportation modes to affected districts are based by many factors including the infrastructures, road conditions, the presence of administrative offices as well as the safety of goods and staffs. For instance, Helicopter mode of transportation offers safe time and protects goods and personnel from attacks that could occur by road.
- Trucks, fuels and labor are available all along the supply chain from the main distribution center to the District DC.
- The main DC has sufficient humanitarian reliefs as stated in Table 5 to supply to all affected districts in Ituri, North Kivu and South Kivu.

1. Identification of facility locations

Tables 5 and 6 have listed districts with high conflicts rates. Among the vulnerable areas the three provinces being study, towns or cities of higher population rates are prime candidates for distribution centers (DC). DC (warehouses) needs to be located in area with a relatively stronger security organization with the national police stations and army bases as well as the regional agencies in charge of various services. Other key service includes hospital, clinics and commercial places.

2. Available infrastructures and road conditions

The relief supplies are transported from DC to affected areas using all available transportation modes including trucks, airplanes, helicopters even boats depending on the road conditions, availability, the urgency as well as the quantity and the cost. Many international organizations such as the WFP as well as the government organization such as the military logistics own fleets of trucks, Helicopters and other relevant transportation modes are found in the region available for the mission. Mpita et al. (2016) mentioned the availability of MI-8 Helicopters for relief supplies to remote areas of Shabunda, where roads and other infrastructures are nearly inexistent. In order to determine the best transportation decision for each affected territory in the region, Table 6 set up a scale (good, fair, bad and critical) of evaluation of the infrastructures in the

Table 5 Listed the towns or cities per district with high population, connectivity, warehouses, infrastructures and administrative systems

Provinces	Conflicts districts	Population size	Potential cities	Populated city	Population size
North Kivu	Goma	2,000,000	Goma, Karisimbi	Goma	941,456
	Rutshuru	1,606,357	Rutshuru, Bwito, Bwisha, Kiwanja	Rutshuru	250,000
	Walikale	987,265	Walikale, Bakano, Wanianga	Walikale	16,147
	Beni	916,181	Beni, Beu, Bungulu, Mulekera, Ruwenzori	Beni	129,163
	Lubero	1,063,586	Lubero, Butembo,	Butembo	744,838
	Masisi	711,075	Masisi, Katoyi, Bahunde, Osoo Banyungu	Masisi	18,708
South Kivu	Bukavu	870,954	Bukavu	Bukavu	415,521
	Mwenga	786,961	Mwenga, Wamuzima, Kamituga, Basile, Itombwe	Mwenga	424,000
	Walungu	720,780	Walungu, Ngweshe, Kaziba	Walungu	68,857
	Shabunda	925,733	Shabunda, Bakisi, Wakabango	Shabunda	30,946
	Kalehe	815,326	Biloho, Bahavu, Bunyakiri		
	Uvira	1,181,207	Uvira, Bafulero, Bariva, Plaine of Ruzizi	Uvira	378,736
	Kabare	780,616	Kabare, Ninja	Kabare	37,034
	Fizi	1,022,044	Fizi, Mutambala, Lulenge, Ngandja	Fizi	30,000
Ituri	Mambasa	746,287	Mambasa, Madidi, Nia Nia, Koko	Mambasa	249,073
	Irumu	1,288,343	Bunia, Nyankunde	Bunia	366,126
	Aru	1,502,726	Aru, Ariwara, Kakwa	Aru	94,267
	Mahagi	2,636,284	Mahagi, Reti, Walendu Watsi	Mahagi	67,954
	Djugu	2,824,047	Djugu, Mongbwalu, Walendu, Bahema, Mabisa	Djugu	28,061

Table 6 Evaluation scale of infrastructures, road conditions, administrative offices, security and health

	Infrastructures	Road conditions	Administrative offices	Security	Health
Good	Road, airport, marine, train	Average speed of 100 km/h	All necessary government offices operating on sites	Well equipped police stations, army bases	Well equipped health facilities with qualified personnel
Fair	Road, airport,	Average speed of 40–60 km/h	Just enough government offices are operational	Barely equipped police stations, army bases	Barely equipped health facilities with limit qualified personnel
Bad	Airport	Average speed of 5–15 km/h	Limited number of regional offices operating on sites	Poorly equipped police stations, army bases	Limited health facilities with no qualified personnel
Critical	None	Broken roads and bridges	No regional offices operating on sites	No army bases, poor security presence	No health facilities present

affected areas, the road conditions leading to the affected areas, the presence of administrative offices in the areas affected, the security of goods and personnel during the travelling, the storage and distribution. Finally, the evaluation also determines the scale of the presence of health care facilities, staffs, medication and equipment to the population of the affected area.

From the evaluation scale framework listed in Table 6, the next Table 7 evaluates the state of each of those relief transportations preconditions province by province. The outcome shows the advance destruction states of some regional roads leading to affected areas as well as some security challenges.

3. Transportation time and cost

From the evaluation, decisions are made on which transportation modes to be used in each area, taking into account the security of goods and staffs. Poor road conditions and the availability of transportation modes are one of the major issues often faced by relief organizers. Other minor, yet significant hurdles encountered include possible disruptions caused by conflicts. After key transportation factors are established, in order to estimate the demand and the supply quantity of reliefs to candidate cities, Table 8 below estimates the distance from the Main DC to those candidates DC from affected areas:

a. Constraint conditions

Among the assumptions, one is that relief supplies donated from disaster agencies are available at each of the three Distribution Center (Goma, Bukavu and Bunia). From the Distribution Centres, supplies are sent to prepositioned hot spot areas in each province. The study also assumed that trucks, cargo planes, helicopters and personnel are available and ready for the delivery when needed. Each potential hot spot areas are assumed to possess warehouses capable of storing relief supplies. The supply and demand quantities for the affected areas were

determined based on historical data and the amount of vulnerable population size.

From Table 7, the following are areas are listed as vulnerable areas for conflicts and candidate relief destination: South Kivu Province (Bukavu, Mwenga, Walungu, Kahele, Shabunda, Uvira, Kabare and Fizi), North Kivu Province (Goma, Beni, Butembo, Rutshuru, Walikale and Masisi), and Ituri Province (Bunia, Mambasa, Aru, Mongbwalu, and Mahagi). Each province chief town is the main Warehouse [Bukavu in South Kivu ($W1$), Goma in North Kivu ($W2$) and Bunia in Ituri ($W3$)] or Distribution Centre (DC).

The demand for each province is represented respectively by the following symbols: **$Wd1$** ($Ds_1, Ds_2, Ds_3, Ds_4, Ds_5, Ds_6, Ds_7$ and Ds_8), **$Wd2$** ($Dn_1, Dn_2, Dn_3, Dn_4, Dn_5$ and Dn_6) and **$Wd3$** (Di_1, Di_2, Di_3, Di_4 and Di_5). The supply for each province is represented respectively by the following symbols: **$Ws1$** ($Ss_1, Ss_2, Ss_3, Ss_4, Ss_5, Ss_6, Ss_7$ and Ss_8), **$Ws2$** ($Sn_1, Sn_2, Sn_3, Sn_4, Sn_5$ and Sn_6) and **$Ws3$** (Si_1, Si_2, Si_3, Si_4 and Si_5). Each variable relates to those following areas: Bukavu ($W1, Ds1, Ss1$), Mwenga ($W1, Ds2, Ss2$), Walungu ($W1, Ds3, Ss3$), Kahele ($W1, Ds4, Ss4$), Shabunda ($W1, Ds5, Ss5$), Uvira ($W1, Ds6, Ss6$), Kabare ($W1, Ds7, Ss7$), Fizi ($W1, Ds8, Ss8$), Goma ($W2, Dn1, Sn1$), Beni ($W2, Dn2, Sn2$), Butembo ($W2, Dn3, Sn3$), Rutshuru ($W2, Dn4, Sn4$), Walikale ($W2, Dn5, Sn5$), Masisi ($W2, Dn6, Sn6$), Bunia ($W3, Di1, Si1$), Mambasa ($W3, Di2, Si2$), Aru ($W3, Di3, Si3$), Mongbwalu ($W3, Di4, Si4$) and Mahagi ($W3, Di5, Si5$). Table 9 below assumes the demand and supply quantity for areas based on the population size and the estimated displaced population.

In order to optimize the disaster supply, the Transportation Time must be reduced while the Cost must be kept minimal. By reducing the delivery time, the number of warehouses readiness and victim's survival are increased. The Table 10 below give full details on the average transportation time C_{ij}^2 (h/piece) and the average transportation cost C_{ij}^1 (US Dollar/piece) within Eastern DRC.

Table 7 Province by province evaluation of infrastructures, road conditions, administrative offices, security and health

Province	Conflicts area	Town	Population size	Infrastructures	Road conditions	Administrative offices	Security	Health
South Kivu	Bukavu	<i>Bukavu</i>	870,954	Road, airport, marine	Fair	Good	Good	Good
	Mwenga		806,940	Road, marine, airport	Bad	Fair	Fair	Bad
	Walungu	<i>Walungu</i>	85,000	Road, airport, marine	Fair	Fair	Fair	Fair
	Kalehe	<i>Kahele</i>	462,465	Road, airport, marine	Fair	Fair	Fair	Fair
	Shabunda	<i>Shbunda</i>	923,000	Road, airport, marine	Critical	Bad	Fair	Bad
	Uvira	<i>Uvira</i>	378,736	Road, marine	Fair	Fair	Bad	Fair
	Kabare	<i>Kabare</i>	37,034	Road, airport, marine	Fair	Fair	Fair	Fair
	Fizi	<i>Fizi</i>	30,000	Road, airport, marine	Bad	Bad	Critical	Bad
North Kivu	Goma	<i>Goma</i>	2,000,000	Road, marine, airport	Good	Good	Good	Good
	Beni	<i>Beni</i>	916,181	Road and flights	Good	Fair	Bad	Bad
	Lubero	<i>Butembo</i>				Fair	Bad	Bad
	Rutshuru	<i>Rutshuru</i>				Fair	Bad	Fair
	Walikale	<i>Walikale</i>				Fair	Critical	Bad
Ituri	Masisi	<i>Masisi</i>	18,708	Road and flights	Fair	Fair	Critical	Bad
	Irumu	<i>Bunia</i>	366,126	Road, airport, marine	Fair	Fair	Fair	Fair
	Mambasa	<i>Mambasa</i>	249,073	Road and flights	Bad	Fair	Bad	Fair
	Aru	<i>Aru</i>	94,267	Road and flights	Fair	Fair	Fair	Fair
	Djugu	<i>Mongbwalu</i>	28,061	Road, airport, marine	Bad	Critical	Critical	Critical
	Mahagi	<i>Mahagi</i>	67,954	Road, airport, marine	Fair	Fair	Bad	Bad

Table 8 Province by province distance from chief town to the candidate distribution centre (km)

Provinces	Main DC	Distribution centre candidates distance (km)							
South Kivu	Bukavu	<i>Bukavu</i>	<i>Mwenga</i>	<i>Walungu</i>	<i>Kahele</i>	<i>Shabunda</i>	<i>Uvira</i>	<i>Kabare</i>	<i>Fizi</i>
	Distance	5	438	68	71	689	131	13	250
North Kivu	Goma	Goma	Beni	Butembo	Rutshuru	Walikale	Masisi		
	Distance	6	334	285	71	413	78		
Ituri	Bunia	Irumu	Mambasa	Aru	Mongbwalu	Mahagi			
	Distance	61	173	240	175	159			

To be noted that the travelling time by road in the Eastern part of DRC is estimated at 40 km/h.

Road transportation is generally cheaper in comparison to air transportation. The gap between those two modes of transportation is excessively large in the DRC region most

likely due to the bad state of most roads in the country and the limited amount of well equipped, well ran airports and well-maintained planes and helicopters. Furthermore, ‘Transportation of goods using trucks in the SADC region cost between US\$ 120 and US\$ 280 per tonne, while air

Table 9 Demand quantities

Demand quantities								
<i>S1</i>								
DQ	D <i>s</i> ₁	D <i>s</i> ₂	D <i>s</i> ₃	D <i>s</i> ₄	D <i>s</i> ₅	D <i>s</i> ₆	D <i>s</i> ₇	D <i>s</i> ₈
Quantity	75	110	17	26	175	40	15	75
SQ	S <i>s</i> ₁	S <i>s</i> ₂	S <i>s</i> ₃	S <i>s</i> ₄	S <i>s</i> ₅	S <i>s</i> ₆	S <i>s</i> ₇	S <i>s</i> ₈
Quantity	45	95	17	26	150	45	15	65
<i>S2</i>								
DQ	D <i>n</i> ₁	D <i>n</i> ₂	D <i>n</i> ₃	D <i>n</i> ₄	D <i>n</i> ₅	D <i>n</i> ₆		
Quantity	40	150	70	30	85	80		
SQ	S <i>n</i> ₁	S <i>n</i> ₂	S <i>n</i> ₃	S <i>n</i> ₄	S <i>n</i> ₅	S <i>n</i> ₆		
Quantity	40	110	52	35	65	70		
<i>S3</i>								
DQ	D <i>i</i> ₁	D <i>i</i> ₂	D <i>i</i> ₃	D <i>i</i> ₄	D <i>i</i> ₅			
Quantity	75	18	45	110	80			
SQ	S <i>i</i> ₁	S <i>i</i> ₂	S <i>i</i> ₃	S <i>i</i> ₄	S <i>i</i> ₅			
Quantity	75	18	45	65	80			

SC supplier code, SQ supply quantity (piece/day), DQ demand quantity (piece/day)

transportation varies between US\$ 4000 and US\$ 6000 per tonne' (Ranganathan and Foster 2011). It needs to be noted that due to the advance degradation of many transportation infrastructures in DRC, the cost of transportation is a bit higher in comparison to other regional countries.

4. Transportation problem

Transportation problem was expressed by Prasad et al. (1993) in the mathematical language. With all consideration, a load of products is transported from each of m sources to n destinations. The sources are volunteers donating toward relief organization facilities, warehouses, or supply points, characterized by available capacities a_i , for $i = 1, 2, 3, 4, 5, 6, 7, \dots, m$. The destinations represent disaster consumption facilities, warehouses, or demand points, characterized by required levels of demand b_j , for $j = 1, 2, 3, 4, 5, 6, 7, \dots, n$. For the transportation time and cost to meet the minimum value simultaneously, the linear programming (LP) minimization z_q needs to be formulated as follow:

$$\min z_q = \sum_{i=1}^m \sum_{j=1}^n C_{ij}^q X_{ij}, \quad q = 1, 2 \quad (3.1)$$

Subject to:

$$\sum_{j=1}^n X_{ij} = a_i, \quad i = 1, 2, 3, 4, 5, 6, 7, \dots, m \quad (3.2)$$

$$\sum_{i=1}^m X_{ij} = b_j, \quad j = 1, 2, 3, 4, 5, 6, 7, \dots, n \quad (3.3)$$

$$X_{ij} \geq 0, \quad \forall i, j \quad (3.4)$$

With $C_{ij}(t)$ as the unit cost of transportation from supply point m ($i = 1, 2, \dots, m$) to demand point j ($j = 1, 2, \dots, n$) when the duration allowed for the transportation is t units and the destination quantities of each countries q units. Now, setting X_{ij} to be the variable denoting the amount transported from supply point i to demand point j , let a_i be the availability at source points i and b_j the demand at demand point j .

The transportation problem (TP) input data could be expressed as intervals instead of point values. According to Jimenez and Verdegay (1998), interval is needed when uncertainty exist in data problem which are often the case in a disaster response situation. And decision makers are more comfortable expressing it as intervals. In this exercise, Jimenez and Verdegay (1998) have considered the TP in which intervals appear only in the constraint set, i.e., in the supplies, demands capacities, by means of equality constraints. The formula could be interpreted as follow:

$$\text{Minimize } \sum_{i=1}^m \sum_{j=1}^n C_{ij}^q X_{ij}, \quad q = 1, 2 \quad (3.5)$$

Subject to:

$$\sum_{j=1}^n X_{ij} = A_i, \quad i = 1, 2, 3, 4, 5, 6, 7, \dots, m \quad (3.6)$$

$$\sum_{i=1}^m X_{ij} = B_j, \quad j = 1, 2, 3, 4, 5, 6, 7, \dots, n \quad (3.7)$$

$$X_{ij} \geq 0, \quad \forall i, j \quad (3.8)$$

where $A_i = [a_i^1, a_i^2]$, $i = 1, 2, 3, 4, 5, 6, 7, \dots, m$, $B_j = [b_j^1, b_j^2]$, $j = 1, 2, 3, 4, 5, 6, 7, \dots, n$ are intervals of possible values for the supplies, demands capacities, respectively, and relation $=$ is formally defined as

$$w =_1 [a, b] \overline{\text{def}} \exists z \in [a, b] : w = z. \quad (3.9)$$

4 Results and findings

With the estimated demand and supply quantity, the estimated cost per tonnes for transportations and the estimated time and distances; the following decision scenarios were developed:

Table 10 Average transportation time transportation cost and Average

Supplier code	Average transportation cost								
	(US dollar/piece) C_{ij}^1								
	1. Air transportation: between US\$ 4000 to US\$ 6000								
	2. Route transportation: between US\$ 120 to US\$ 280								
Ws1	Ss_1	Ss_2	Ss_3	Ss_4	Ss_5	Ss_6	Ss_7	Ss_8	
SOUTH KIVU	45	95	17	26	150	45	15	65	SQ (piece) a_i
	–	\$5400	\$4895	–	\$5520	\$4950	–	\$5150	Air trans C_{ij}^1
	\$145	\$240	\$190	\$200	\$275	\$205	\$150	\$220	Road trans C_{ij}^1
Ws2	Sn_1	Sn_2	Sn_3	Sn_4	Sn_5	Sn_6			
NORTH KIVU	40	110	52	35	65	70			SQ (piece) a_i
	–	\$4950	\$4810	\$4800	\$5250	\$4960			Air trans C_{ij}^1
	\$160	\$210	\$205	\$225	\$255	\$230			Road trans C_{ij}^1
Ws3	Si_1	Si_2	Si_3	Si_4	Si_5				
ITURI	75	18	45	65	80				SQ (piece) a_i
	\$4560	\$5045	\$5190	\$4620	\$5150				Air trans C_{ij}^1
	\$165	\$180	\$235	\$240	\$255				Road trans C_{ij}^1
Average transportation time									
C_{ij}^2 (h/piece)									
Ws1	Ss_1	Ss_2	Ss_3	Ss_4	Ss_5	Ss_6	Ss_7	Ss_8	
SOUTH KIVU	45	95	17	26	150	45	15	65	SQ (piece)
	–	0.4	0.28	–	0.47	0.38	–	0.5	Air trans C_{ij}^2
	0.15	9.55	2.08	2.46	18.36	2.85	0.45	8.12	Road trans C_{ij}^2
Ws2	Sn_1	Sn_2	Sn_3	Sn_4	Sn_5	Sn_6			
NORTH KIVU	40	110	52	35	65	70			SQ (piece)
	–	0.55	0.5	0.32	0.42	0.32			Air trans C_{ij}^2
	0.75	4.81	4.02	4.58	10.63	4.16			Road trans C_{ij}^2
Ws3	Si_1	Si_2	Si_3	Si_4	Si_5				
ITURI	75	18	45	65	80				SQ (piece)
	0.3	0.4	0.5	0.3	0.4				Air trans C_{ij}^2
	2.54	6.13	9.24	2.31	5.78				Road trans C_{ij}^2

4.1 Decision scenario 1: computing the transportation time and cost from available air links and from available connecting roads

4.1.1 Air links connectivity

All candidate facility locations in each province are connected to their Chief Town either airplanes or by a Helicopters. To be noted that this study previously assumed that both airplanes and Helicopters were available to transport prepositioned goods. Table 11 shows the calculated supply transportation cost (\$) and time (days) for each candidate location. The outcome reveals that under the estimated air cost and supply quantity, it will take 17.41 days to air

supply to all facility locations with the overall transportation cost of \$28,826,745.

4.1.2 Road connectivity

All candidate facility locations are connected to each province' chief town by trucks and other transportation modes that use roads. With the assumption that the region has enough available trucks at each province chief town, ready for transportation, goods are transported to destinations with the conditions that roads are in good condition and secure for goods and staffs. Other minor concern for road travelers includes health services and administrative officers. Table 12 reveals that under the estimated air cost

Table 11 Average air transportation cost and average transportation time

Warehouses	W1											
Supply code	Ss1	Ss2	Ss3	Ss4	Ss5	Ss6	Ss7	Ss8				
Given average transportation time	0.15	9.55	2.08	2.46	18.36	2.85	0.45	8.12				
Given average transportation cost	\$145	\$240	\$190	\$200	\$275	\$205	\$150	\$220				
Selected transport method	Land	Land	Land	Land	Land	Land	Land	Land				
Max supply quantity	45	95	17	26	150	45	15	65				
Supply transport cost	\$6525	\$22,800	\$3230	\$5200	\$41,250	\$9225	\$2250	\$14,300				
Transport time (hours)	6.75	907.25	35.36	63.96	2754	128.25	6.75	527.8				
Transport time (days)	0.28	37.80	1.47	2.67	114.75	5.34	0.28	21.99				
	W2						W3					Total
	Sn1	Sn2	Sn3	Sn4	Sn5	Sn6	Si1	Si2	Si3	Si4	Si5	
Given average transportation time	0.75	4.81	4.02	4.58	10.63	4.16	2.54	6.13	9.24	2.31	5.78	
Given average transportation cost	\$160	\$210	\$205	\$225	\$255	\$230	\$165	\$180	\$235	\$240	\$255	
Selected transport method	Land	Land	Land	Land	Land	Land	Land	Land	Land	Land	Land	
Max supply quantity	40	110	52	35	65	70	75	18	45	65	80	
Supply transport cost	\$6400	\$23,100	\$10,660	\$7875	\$16,575	\$16,100	\$12,375	\$3240	\$10,575	\$15,600	\$20,400	\$2,47,680
Transport time (hours)	30	529.1	209.04	160.3	690.95	291.2	190.5	110.34	415.8	150.15	462.4	Max time
Transport time (days)	1.25	22.05	8.71	6.68	28.79	12.13	7.94	4.60	17.33	6.26	19.27	319.58

and supply quantity, it will 319.58 days to transport by road all the relief supply to facility locations with the overall transportation cost of \$247,680. Close studies to the Table 12, few bottlenecks in term of transportation time surfaces. Among them, the Table 12 shows that it takes 114.75 days to supply relief to Shabunda (Ss5) alone from Bukavu (W1) due to poor road condition.

The graph below (Fig. 6) shows that transporting goods via road is way cheaper than transporting goods via air although it takes longer than it should due to the poor road conditions. As mentioned, from Bukavu (W1) to Shabunda (Ss5) road condition was described on the evaluation Table 7 as “critical”. Such road had led to the increase of transportation Time and Cost while other long-distance road to Walikale (Sn5), with a “fair” road (Table 7) from Goma (W2) has been reach quicker. Both Figs. 6 and 7 show respectively that road transportation is cheaper and longer than the Air transportation.

Both road and air connectivity offer a contrasting outcome to the research intent. The next decision scenario intends to minimize both road and the air transportation.

4.2 Decision scenario 2: computing the transportation time and cost based on the province by province evaluation of road conditions, administrative offices, security and health (as stated in Table 7)

The decision scenario intends to use the outcome of the first scenario in order to development a model that minimizes the cost and the time. Scenario one first revealed that road transportation is ideal for the humanitarian delivery for many reasons: (1) all facility locations are connected by road, (2) road transportation is cheaper. However, road transportation in DRC brings along many challenges, among many road conditions and the security of goods humanitarian personnel’s during the operation. In order to alleviate these challenges, this research developed a framework in the Table 6 that evaluates each of these challenges and scale them from “good” to “critical”. Then Table 7 evaluates each facility locations targeted in this study and each area was scaled according to the challenge it is facing at the time this study is conducted. In the next point, the list of challenges scaled in Table 7 is analyzed

Table 12 Average transportation cost and average transportation time

Warehouses	W1							
	Ss1	Ss2	Ss3	Ss4	Ss5	Ss6	Ss7	Ss8
Supply code								
Given average transportation time	0.05	0.4	0.28	0.16	0.47	0.38	0.17	0.5
Given average transportation cost	\$4010	\$5400	\$4895	\$4050	\$5520	\$4950	\$4230	\$5150
Selected transport method	Air	Air	Air	Air	Air	Air	Air	Air
Max supply quantity	45	95	17	26	150	45	15	65
Supply transport cost	\$1,80,450	\$5,13,000	\$83,215	\$1,05,300	\$8,28,000	\$2,22,750	\$63,450	\$3,34,750
Transport time (hours)	2.25	38	0	4.16	70.5	17.1	2.55	32.5
Transport time (days)	0	1.58	0.00	0	2.94	0.71	0.00	1.35
Total								
	W2				W3			
	Sn1	Sn2	Sn3	Sn4	Sn5	Sn6	Si1	Si2
Given average transportation time	0.06	0.55	0.5	0.32	0.42	0.32	0.3	0.4
Given average transportation cost	\$4120	\$4950	\$4810	\$4800	\$5250	\$4960	\$4560	\$5045
Selected transport method	Air	Air	Air	Air	Air	Air	Air	Air
Max supply quantity	40	110	52	35	65	70	75	18
Supply transport cost	\$1,64,800	\$5,44,500	\$2,50,120	\$1,68,000	\$3,41,250	\$3,47,200	\$3,42,000	\$90,810
Transport time (hours)	2.4	60.5	26	11.2	27.3	22.4	22.5	7.2
Transport time (days)	0	2.52	1.08	0.47	1.14	0.93	0.94	0.30
Max time								
17.41								

Fig. 6 Road transportation cost versus air transportation cost (\$) **Fig. 7** Road transportation versus air transportation time (days) **Table 13** Counting of evaluated areas in Table 3.7

	Good	Fair	Bad	Critical	Total
Road conditions	Sn1, Sn2, Sn3	Ss1, Ss3, Ss4, Ss6, Ss7, Sn4, Sn5, Sn6, Si1, Si3, Si5	Ss2, Ss8, Si2, Si4	Ss5	19
Administrative offices	Ss1, Sn1, Sn3	Ss2, Ss3, Ss4, Ss6, Ss7, Sn2, Sn3, Sn4, Sn5, Sn6, Si1, Si2, Si3, Si5	Ss5, Ss5	Si4	19
Security	Ss1, Sn1, Sn3	Ss2, Ss3, Ss4, Ss5, Ss7, Si1, Si3	Ss6, Sn2, Sn3, Sn4, Si2	Ss8, Sn5, Sn6, Si4	19
Health	Ss1, Sn1, Sn3	Ss3, Ss4, Ss6, Ss7, Sn4, Si1, Si2, Si3	Ss2, Ss5, Ss8, Sn2, Sn3, Sn5, Sn6, Si5	Si4	19
Total	9	40	19	7	76

and the feedback is useful in determining areas that are not “road worthy” and that require different modes.

4.2.1 Analysis of the evaluation

Table 13 below shows the list of key challenges faced by relief organizations during humanitarian supply chain and what category each area is scaled under. For instance, the “road condition” challenge fall under a “good” scale in Goma (Sn1), Beni (Sn2) and Butembo (Sn3) while the scale was “critical” in Shabunda (Ss5). In total, Table 13 shows that most road conditions, administrative offices, security and health care facilities in the areas being studied

are “fair” with 52.63%, while the “good” are 11.84%, “Bad” 25% and “critical” 9.21%.

Table 14 below shows the percentage for scale according to the challenge. This exercise allows the research to identify the percentage each challenge has on the total number of areas being targeted. For instance, 21.05% of humanitarian supply chain operation is operated under “critical” security threat due to the conflicts faced in the region.

A prepositioned humanitarian supply chain in a conflict zone requires all listed challenges in Table 14 being taken into accounts. However, when zooming into the transportation of humanitarian reliefs by roads from a source to

Table 14 Identification of each scale percentage

	Good (%)	Fair (%)	Bad (%)	Critical (%)	Total (%)
Road conditions	15.80	57.90	21.05	5.30	100
Administrative offices	10.52	73.68	10.52	5.30	100
Security	10.52	36.84	26.31	21.05	100
Health	10.52	42.11	42.11	5.30	100
Total	11.84	52.63	25	9.21	100

destinations, two key challenges are necessary to take into account among the four challenges are the “road conditions” and the “security”. Looking into the road condition, Table 14 shows that 73.70% of roads are in the “good” to “fair” condition while the remaining 26.3% were “bad” to “critical” condition. Furthermore, only 47.36% of road transportation to facility locations is view as done in “good” security and “fair” security. Unfortunately, most facility locations (52.64%) are located in areas that do not guarantee security to humanitarian goods and personnel.

4.2.2 Application of the evaluation

In order to ensure the safety of the reliefs, the goods are delivered at the minimum costs and time; this study has applied the evaluation outcomes defined in Tables 13 and 14 into the road and Air transportation results found in Tables 11 and 12. By integrating the road conditions” and the “Security” evaluation into the model, the research minimizes both costly and lengthy deliveries while ensuring that reliefs reaches destinations safely. Such is achieved by prioritizing road deliveries to all destination cities except in the case of “bad” or “critical” road conditions and deliveries to unsafe areas. Table 15 and Fig. 8 show that by opting for air transportation in the delivery to areas with “bad” to “Critical” road conditions, or to those with record security

Table 15 Outcomes of both decision scenarios

	Price (\$)	Time (day)
Air transportation	\$28,826,745	17.63
Road transportation	\$247,680	319.58
Air and road combined	\$2465,105	127.25

Fig. 8 Price versus time of air, road and both combined transportation

challenges, the Transportation price increases from \$247,680 to \$2,465,105 while the delivery time decreases from the initial 320 days to 128 days. Combining however Air Transportation to the Road Transportation to challenged places decreases the air transportation cost from \$28,826,745 to a combined cost of \$2,465,105.

5 Conclusion and future works

Both Road and Air connectivity offer a contrasting outcome to the research objectives. For the Road transportation, although cheaper and ideal for the “cash trapped” humanitarian relief operations, it takes longer to deliver goods due to poor road conditions at some trajectories while the relief security also represent a serious challenge. The Air Transportation, although it ensures that goods are delivered safely, efficiently and at a small-time frame, however it is too pricy.

With this research intent of prepositioning goods transported to facility locations, there is therefore no rush to use air transportation with its benefices of being faster and reliable but also its consequences of costing nearly 12 times more than road transportation. With prepositioned facility locations, road transportation, except in the case of poor road conditions or lack of security to staff and goods, should be the main transportation mode especially during humanitarian supply chain. This study outcomes shows that (1) by using roads to areas evaluated as “good” or “Fair” and (2) by opting for air transportation to areas evaluated as “Bad” or “critical” and those with the record of security issues, this research will minimize the transportation time and the cost simultaneously.

Like the Democratic Republic of Congo, many countries and region in the world are struggling with conflicts that

has caused logistical and supply chain challenges. Applying this model not only minimises the time and cost for transportation, but also assist decision makers select the best relief transportation decisions.

Future works may improve the feasible solution by looking into the unbalanced transportation problems in case which total demand is not equal to the total supply. For instance, when demand is less than supply or when the demand is greater than supply. Other areas of interest in future studies are in incorporating all key humanitarian supply chain challenges listed in this study into one model. Also, researches could look at the risk of delivering relief by road despite of the 52.64% security threat faced by humanitarian goods and personnel.

References

- Balcik B, Beamon BM (2008) Facility location in humanitarian relief. *Int J Logist Res Appl* 11(2):101–121
- Beamon BM (2004) Humanitarian relief chains: issues and challenges. In: *Proceedings of the 34th international conference on computers and industrial engineering*, vol 34, issue 1. University of Washington, Seattle, WA, pp 77–82
- Campbell AM, Jones PC (2011) Prepositioning supplies in preparation for disasters. *Eur J Oper Res* 209(2):156–165
- Caunhye AM, Nie X, Pokharel S (2011) Optimization models in emergency logistics: a literature review. *Soc Econ Plan Sci* 41(1):4–13
- Centre of research on the Epidemiology of Disasters Website (EM-DAT CRED) (2016) Southern Africa disasters database. 26 Sep 2013. <http://www.em-dat.net>
- Counsel of Foreign Relations (2020). <https://www.cfr.org/interactive/global-conflict-tracker/conflict/violence-democratic-republic-congo>. Accessed 15 Jan 2020
- Degener P, Gössling H, Geldermann J (2013) Decision support for the location planning in disaster areas using multi-criteria methods. In: *International ISCRAM conference*, vol 10, issue 1. Baden-Baden, Germany, pp 278–283
- Duran S, Keskinocak P, Gutierrez MA (2011) Pre-positioning of emergency items worldwide for CARE international. *Pre-positioning Emerg Suppl* 41(3):223–237
- Hale T, Moberg CR (2005) Improving supply chain disaster preparedness: a decision process for secure site location. *Int J Phys Distrib Logist Manag* 35(3):195–207
- International Monetary Fund (2019) Democratic republic of Congo. IMF Country. Report No. 19/286
- Jimenez F, Verdegay JL (1998) Uncertain solid transportation problems. *Fuzzy Sets Syst* 100(1):45–57
- Kembro J (2012) Implementing strategic stock to improve humanitarian aid response. *Emerald Emerg Mark Case Stud* 2(7):1–6
- Kim BS, Opi PF, Lee WS (2011) A stock prepositioning model to maximize the total expected relief demand of disaster areas. *Oper Supply Chain Manag* 6(2):103–110
- Kovács G, Spens KS (2009) Identif Chall Humanit Logist 39(6):506–528
- Kunz N, Reiner G, Gold S (2013) Investing in disaster management capacities versus pre-positioning inventory: a new approach to disaster preparedness. *Int J Prod Econ* 157(1):261–272
- Mpita SN, Yadavalli VSS, Bean WL (2016) Integrated facility location planning and demand assessment for humanitarian logistics: a case study in the Democratic Republic of the Congo. *Manag Dyn* 25(1):34–50
- Nahleh Y, Kumar A, Daver F (2013) Facility location problem in emergency, international journal of mechanical, aerospace, mechatronic, and manufacturing. *Engineering* 7(10):2113–2118
- OCHA (United Nations Office for the Coordination of Humanitarian Affairs) RDC (2019) Ebola in the Democratic Republic of the Congo. Health emergency update. <https://www.who.int/emergencies/diseases/ebola/drc-2019>. Accessed 15 Jan 2020
- Oxfam International (2014) Oxfam annual report 2014–2015. https://www-cdn.oxfam.org/s3fs-public/file_attachments/story/oxfam_annual_report_2014_-_2015_final.pdf
- Prasad VR, Nair KPK, Aneja YP (1993) A generalized time-cost trade-off transportation problem. *J Oper Res Soc* 1243–1248
- Ranganathan R, Foster V (2011) The SADC's infrastructure: a regional perspective. Policy research. World Bank, Africa Region
- RDC Humanitaire (2020) (online). <https://www.humanitarianresponse.info/fr/operations/democratic-republic-congo>. Accessed 15 Jan 2020
- Roh S, Jang H, Han C (2013) Warehouse location decision factors in humanitarian relief logistics. *Asian J Shipp Logist* 29(1):103–120
- Root S, Qu X, Samanlioglu F, Davis L (2012) Inventory planning and coordination in disaster relief efforts. *Int J Prod Econ* 141(2):561–573
- Starr MK, Van Wassenhove LN (2014) Introduction to the special issue on humanitarian operations and crisis management. *Production operations and crisis management. Prod Oper Manag* 23(6):925–937
- Strawderman L, Eksioglu B (2009) The role of intermodal transportation in humanitarian supply chains final report
- Tatham P, Houghton L (2011) The wicked problem of humanitarian logistics and disaster relief aid. *J Humanit Logist Supply Chain Manag* 1(1):15–31
- Thomas A (2004) Elevating humanitarian logistics. *Int Aid Trade Rev* 1(1):102–106
- Timperio G, Panchal GB, Samvedi A, Goh M, De Souza R (2017) Decision support framework for location selection and disaster relief network design. *J Humanit Logist Supply Chain Manag* 7(3):222–245
- Tomasini RM, Van Wassenhove LN (2009) From preparedness to partnerships: case study research on humanitarian logistics. *Int Trans Oper Res* 16(5):549–559
- Turnquist MA, Rows CG (2009) Pre-positioning of emergency supplies for disaster response. *Transp Res Part B* 44(4):521–534
- Van Wyk E, Yadavalli VSS, Carstens H (2013) Decision support in supply chain management for disaster relief in Somalia. In: *New paradigms in internet computing*, vol 1, issue 1. Springer, Berlin, Heidelberg, pp 13–22
- WFP (2012) Concept of operations—DRC North and South Kivu. World Food Programme (online). <http://www.logcluster.org/sites/default/files/documents/conops-north-and-south-kivu-121205>. Accessed 11 Nov 2015
- WFP (2013). https://reliefweb.int/sites/reliefweb.int/files/resources/sigma1_2016_en.pdf. Accessed 15 Mar 2020
- World Bank (2020) (Online). <https://www.humanitarianresponse.info/fr/operations/democratic-republic-congo>. Accessed 15 Jan 2020
- World Vision (2018). <https://www.worldvision.org/disaster-relief-news-stories/worst-disasters-2018>. Accessed 15 Jan 2020

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