RESCUE AND RELIEF OPERATION AFTER A DEVASTATING FIRE ACCIDENT: A HUMANITARIAN LOGISTICS-BASED MODELING APPROACH

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ABSTRACT

The frequency of fire disasters is fortunately low, but planning the logistics and related routings for rescue, relief, and rehabilitations operations are major issues in launching any humanitarian assistance. In addition to the logistics planning issues, the reasons for the occurrence of the fire disasters should also be determined so that measures may be put in place to prevent future disasters as well as any potential consequences that may occur after the fire is extinguished. Most cities have efficient fire departments quipped with resources and fire brigades to initiate immediate measures to control the fire and to start the rescue operation. Moreover, most governments take steps to provide relief and rehabilitation assistance to the affected population. Rescue, relief, and rehabilitation steps in traffic-congested cities, especially in heavily populated areas with many businesses and markets, are highly challenging. This research proposes a mathematical modeling-based approach for planning the transportation of relief and rescue resources; conducting relief and rescue operations; and outlining measures to prevent future recurrences. The model will be illustrated using the chemical explosion-fed fire which occurred on February 20, 2019 in the old part of Dhaka in Bangladesh.

Keywords: Humanitarian logistics, rescue and relief operations, routing of resources, fire disasters, logistics in traffic-congested areas

1. INTRODUCTION

Natural and manmade disaster occurrences have been increasing from year to year. From 1900 to the 2019 over 2000 mass disasters have been reported, and from 2000 to 2018 nearly 81.7 million people have been affected by various disasters with 1.3 million reported causalities (CRED, 2018). Humanitarian logistics (HL) plays a crucial role in providing relief to the disaster-affected areas and in mitigating the disaster impacts. HL literature addresses pre-disaster readiness planning for relief operation, post-disaster rescue operation and recovery support planning. Pre-disaster planning considerations include prepositioning of assets in advance to support timely relief operations (Arnette and Zobel, 2019). Such pre- and post-disaster planning, including recovery support preparation, may also be considered as the preparation for emergency management by including measures for mitigation and safety (Wagner and Agarwal, 2014). Emergency situations and associated emergency and safety measures largely depend on the environment where the disaster occurs. Fire breakouts in densely populated urban areas can easily propagate to the adjacent buildings and engulf an entire area (Waheed, 2014; Navitas, 2014). As such, fire disasters are responsible for extensive damage to the urban environment and can cause numerous fatalities (Himoto and Tanaka, 2008). Occurrences of such fire disasters and measures for mitigation and relief operations are quite different in different situations, causing any pre-planning exercise to consider numerous scenarios (Jain and McLean, 2008). NGOs often come forward to support disaster relief operations as evidenced by the media stories of Dhaka 2019 fire. But such supports are usually insignificant compared to the requirements. Government organizations play a major role in disaster relief operations (Apte *et al.*, 2016). In Bangladesh, a government organization has been founded to be responsible for pre-disaster planning and post-disaster mitigation steps. In a heavily populated city with traffic-congested streets the challenging issues include the handling of disaster situations, post disaster rescue operations, recovery planning in addition to planning measures for recurrence prevention. Since handling of disaster situations, post disaster rescue and relief operations and recovery planning need collection of relief items and resources, effective logistics planning for the storage of relief items and transporting them to the affected areas through the transportation network is crucial. For optimum HL planning in a traffic-congested city like Dhaka the following steps are required: i) establishing an emergency monitoring cell to keep track of the entire route and to guide the transportation of the relief items based on traffic density, road condition, alternative route options, etc.; ii) defining and following the traffic and suitability indices for each route segment for effectively tackling the congestion and its complexities; iii) deciding the optimum locations and the number of collection centers to receive relief goods and resources from other cities/countries; iv) planning the optimum number of temporary DCs around the disaster-affected areas for storing and staging the relief items to improve the response time (Vanajakumari *et al.*, 2016); and v) selecting the optimum response route. Since Dhaka has established fire and emergency handling stations with equipment, a logical approach should be to study the city map including the feeder roads and streets in the city, the relative positions of existing fire and emergency services, in order to plan the optimum response route. The next challenge is to send suitable resources for fire-fighting and rescue operation in the quickest possible time.

The present research proposes a state of the art HL planning network model that determines the optimum number and location of facilities with available equipment and resources for firefighting, rescue operations, and for receiving such resources from other locations, cities and countries; defines and establishes traffic and suitability indices through a monitoring cell; and includes the indices in the model to improve the planning reliability. The model also provides for alternative route planning and for government intervention in cases where the traffic density and suitability indices are not at the acceptable level. The model objectives are to optimize the costs as well as the response time. Finally, the research explores the reasons for the recent fire disasters and provides some recommendations based on the available literature.

2. REVIEW OF RELEVANT LITERATURE

The literature on HL planning is reasonably rich, but the number of such studies dealing with fire disasters in cities and urban areas is very limited. However, the approach to preplanning of logistics to mitigate fire disasters and relief operations have some commonalities with the general HL planning for other disasters. This literature review is concerned with: a) a select number of general HL planning research works with relevance to the relief operations aspects of this research; b) research on urban and other fire disasters for mitigation and resilience planning; and c) literature on relief operations in similar urban fire disasters.

a) HL planning in general: HL planning is a critical part of effective relief operations in a disaster situation. Apte (2009) defined HL as a special branch of logistics that manages the response supply chain that provides critical supply and services while facing challenges including demand surges, uncertain supplies and critical time windows in the presence of various vulnerabilities and the vast scope and size of the operations. In a densely populated city the challenges, vulnerabilities, and uncertainties have been found to increase in multiple ways (Himoto and Tanaka, 2012; Waheed, 2014; Navitas, 2014). Providing logistical response depends on the predictability of the disasters (Apte, 2009). Fire disasters in urban areas, such as Dhaka, are not predictable. As such preparedness, response, and reconstruction phases of the disaster management operations, as covered in Vanajakumari *et al.* (2016) following Apte (2009), can be applied on a limited scale. In the case of Dhaka fire management, such planning may include identification of existing fire stations that are close to the fire-affected areas to be used as DCs and main DCs. Since government organizations play the major role in disaster relief operations, the recent findings on the rising cost of these operations is a critical factor in government planning in developing countries. According to Apte *et al.*, 2016, based on Jones (2013), the cost has risen from \$16.1B/year in 1992-2002, to \$40.1B/year in 2002-2011.

b) Mitigation and resilience planning for urban and other fire disasters: Himoto and Tanaka (2008) studied the physics of fire spread in densely populated areas and reported that temperature rise and thermal radiation by the building materials are the two reasons out of several others for the quick spread of fire in such areas. In a similar research Himoto and Tanaka (2012) recommended the judicious selection of the nearby buildings by the firefighting teams in preparation for fire suppression and relief materials delivery to effectively extinguish the fire and start the mitigation planning for the disaster affected area. Flame igniting attributes and factors affecting the propagation of fire as studied by Himoto and Tanaka (2008, 2012) including disaster relief operations and suppression resources and strategies applied in wild fire situations are the lessons that may also be applied in urban fire emergency management.

c) Literature on relief operations in similar urban fire disasters: In terms of disaster effects, as well as the complexity of logistics in high density buildings and heavy traffic, the 2019 fire disaster in Dhaka is almost similar in nature to the Karachi, Pakistan, fire studied by Waheed (2014), although the reasons for the fires have been found to be different. In Karachi, the fire started in a garments factory in Baldia, a suburb of Karachi, and resulted in a higher number of casualties due to the poor design of the building as well as the firefighting abilities of the rescue and relief team. Waheed (2014) recommended a comprehensive disaster management plan for improving the current situation.

Based on the brief literature review, effective logistics planning is a crucial requirement for disaster relief operations. Optimally responsive logistics planning should organize the required resources and relief items, identify and establish locations to serve as collection and distribution centers (preparedness), and plan transportation and distribution of relief items (response phase) and resources for mitigation and recovery. It is important to study and understand the reasons for a disaster and take measures to prevent its recurrence.

3. METHODOLOGY

Considering the numerous entry routes to Dhaka to deliver relief and resource items from outside, and the numerous routes for transporting items to hazard-affected areas from the collection centers, this study proposes a mathematical modeling-based approach to the planning of the collection centers at the main entry points and the transportation of the items to the affected areas at a minimum response time. In a city like Dhaka, obstacles such as high traffic density, road accidents, physical road condition, and occasional political processions hinder the orderly flow of transportation. Thus, there is a need to define and set up some indices to monitor the transportation routes as a precondition for the modeling-based optimization of the response time to disaster-affected areas. A mathematical modeling-based approach will facilitate the consideration of such factors and conditions.

To understand the reasons for the occurrence of the fire, the research explores news reports and government circulars published in Dhaka newspapers. However, the study mainly considered the reports and circulars published in *"The Daily Star"*, which is considered to be the most trusted and highly circulated newspaper in the country.

3.1 Problem Statement

Fire disaster management plan: Dhaka has been facing many fire disasters for a long time. The two large fire disasters in recent years are:1) A fire on June 3, 2010 in Nimtoli area of the old Dhaka (as reported in Nimtoli to Chawkbazar, 2019) that killed 117 people and left 150 people with fire burns; 2) A fire on February 21, 2019 in Chawkbazar area of the old Dhaka that killed 71 people (Nimtoli to Chawkbazar, 2019). Both of these incidents drew the attention of the international media, the entire country, the prime minister's office, and the city mayor. Although some actions had previously been taken to prevent the repetition of such incidents, especially after the Nimtoli disaster, the devastating occurrence of the February 21, 2019 incident revealed the ineffectiveness of those actions.

This research is motivated to study and understand the problem from the perspective of the challenges Dhaka has faced with respect to its heavy population density, traffic congestion, and inadequate fire and emergency handling resources and conditions. The study considers a set of emergency handling stations that are also used as collection centers $i \in I$ (henceforth referred to as CNs) for humanitarian relief items and resources, at suitable locations, mostly at the entry points into the city from Dhaka Airport, Port City of Chittagong, Sadarghat (Dhaka Riverport), Khulna Maowa, and Jamuna Bridge highway. These locations are suitable insofar as they are prepared to receive humanitarian relief items (henceforth referred to as HI) and resources for relief operations from other cities and other countries through air, water and multimodal transportation systems. In addition, they are positioned at a relatively closer distance to the old Dhaka city. A set of distribution centers (DCs) $j^w \in J^w$ are also planned to collect relief items transported from the collection centers for distribution in a more focused and planned way to the demand points. Most of the time, such DCs are temporarily organized based on the disaster area's requirements; the existing fire stations, if available around the disaster area, are always a good choice.

This study also estimates the quantity of HI and resources for relief operations based on the affected population in the fire-devastated areas based on Dhaka Census Data. The estimation is based on the expertise of a team of experienced government and non-government emergency relief handling experts, and considers the requirements of relief resource types for 100 persons (20 families) and HI for 5 persons (1family) under various probabilistic scenarios. The model considers city routes based on transportation system junction/transit points centers $j^t \in J^t$ (henceforth referred to as TNs). To overcome the limitations of slow movement, or no-movement of relief items, the model defines a traffic density index (to be monitored by a satellite-based system) to generate alternative routes and to select one with minimum congestion. Finally, the plan allows for the city administration /government to control the traffic, when necessary, to help relief-carrying vehicles to move faster, as if it were an emergency, when alternative options are not good.

The overall objectives are to improve the response time by transporting relief items in the minimum amount of time and cost. Based on the available data from news reports, the research work also attempted to include some recommendations regarding the prevention of fire incidents in the future.

3.2 Notations

Indices

I: set of CNs $i \in I$; *D:* set of HIs $d \in D$; *G*: set of relief items and resources $g \in G$, such as ambulances, fire trucks, axes, tents (henceforth referred to as resources); *M*: set of transportation modes $m \in M$, such as trucks, helicopters, drones, and small trucks; *J:* set of TNs $j \in J$ (TNs include transit centers $j^t \in J^t$, and destination centers/distribution centers (DCs) $j^w \in J^w$; as such, J^w and J^t are the two partitions of the set *J*); *H*: set of fire incident locations (HNs) $h \in H$, or demand points; sometimes it is shown as h^d , the demand nodes (DN); SC: set of scenarios, $sc \in SC$; *T*: set of population types (t=1 child; t=2 adult; t=3 disabled, sick, old) $t \in T$; *L*: locations for obtaining census data(there are five locations that are affected; these are the demand points/nodes represented as $h \in H$ for hazardous locations. Here *h* and *l* are interchangeable).

Decision Variables

a_i: 1, if CN *i* is opened,0 otherwise; ars_{ij}: 1, if route segment *ij* is used to transport relief items between CN *i* and TN *j*, 0 otherwise; $ars_{jj}{}^w$: 1, if route segment $_{j\,j}{}^w$ is used to transport relief items between TN *j* and DC j^w, 0 otherwise; $ars_j{}^w{}_h{}^d$: 1, if route segment $j^w h^d$ is used to transport relief items between DC j^w and demand node h^d, 0 otherwise; $atd_{jj'}$: 1 if the alternative route's traffic density and suitability indices are acceptable for navigation, 0 otherwise; $v_j{}^w$: 1, if DC j^w is opened, 0 otherwise; $x_{id:}$ total humanitarian relief items *d* including food, medicine, treatment aid, clothes collected at CN *i*; y_{ig} relief items and rescue resources *g* collected at CN *i*; $gv_{jj'}$: 1 if government intervention is applied between TNs *j* and *j'* for transporting relief items, 0 otherwise; $flow_{ijgdm}$: flow of relief item *g* and HI *d* from CN *i* to TN *j* using transportation mode *m*; $flow_{jj'gdm}$: flow of relief item *g* and HI *d* from TN *j* to TN *j'* using transportation mode *m* ; $flow_{jj}{}^w{}_{gdm}$: flow of relief item *g* and HI *d* from TN *j* to DC node j^w using transportation mode *m;* $z_j{}^w{}_h{}^d{}_{gdm}$: distribution of relief item *d* and resource *g* using transportation mode *m* from DC j^w to HN h^d); re_{igd}: relief item *d* and resource *g* received at CN *i; res_{ijm}*: response time in minutes for the flow of relief items on the assigned route CN *i* to TN*j* using transportation mode *m*; $res_{jj'm}$: response time in minutes for the flow of relief items on the assigned route segment between two TNs; $res_{jj}{}^w{}_m$: response time in minutes for the flow of relief items on the assigned route from a TN to a DC around the hazard- affected area using transportation mode *m*; $res_j{}^w{}_h{}^d{}_m$: response time from a DC to a demand node at the hazard location; $td_{jj'}$:1, if traffic density index between TNs *j* and *j'* is found acceptable, 0 otherwise;

Parameters:

CAP_i: overall capacity of CN *i* for relief items (HI) and resources *d*; CD_{ijm}: distance between CN *i* and TN *j* in terms of travel time in minutes using transportation mode *m*; $dis_{jj'm}$: distance in minutes between TNs *j* and *j'*; $CPDCj^w{}_{gd}$: capacity of DC j^w for accommodating resource *g* and HI *d;* $dis_{jj}{}^w{}_m$: distance in minutes between TN *j* and DC j^w using transportation mode *m*; $distr_j{}^w{}_h{}^d{}_m$: distance in minutes between TNs j^w and h^d using transportation mode m; CC_d: cost of collecting HI *d*; CR_g cost of collecting resource *g; $po_{lt:}$* population of type *t* in the fire-affected location; Pr_{sc}: probability of scenario *sc;* Pi_{dsc}: estimated rate of requirements of relief item *d*, including food, water, medicine, warm clothes, baby food, safety items (wrapper, shoes per family of 5); Pr_{gsc} estimated rate of requirements of resource *g* for relief operations (rescuing, mitigating, fire extinguishing), and emergency handling resources (fire trucks, cranes, ambulances, drones, helicopters) per 100 persons under scenario *sc*; PB_{sc}: probability for scenario *sc;* $su_{jj'}$: 1,if the road segment between TNs *j* to *j'* is not broken (i.e., the road is clear); thr_d: total HI items collected at the collection nodes CNs; trs_g: total resources g collected at the collection nodes CNs; re_{idg}: total relief items collected at each collection center/node (CN); $TRD_{jj'}$: traffic density as found by the monitoring team between the TNs j to j'; $ACC_{jj'}$ acceptable limit for traffic density index (There is no internationally accepted traffic density index that may be used by the monitoring team in order to advise the relief and emergency operations team to transport relief items to devastated areas quickly. This research defines an easy to determine index considering the equivalent number of vehicles (of standard length L(17') ×(6')=102 sq. ft. area) on a 40 ft. wide×100 ft. long road segment (a 4000 sq. ft. area on any route), which can accommodate a maximum of 40 vehicles. So, the highest threshold limit is 40 vehicles on a 4000 sq. ft. road segment on any Dhaka city route. We may set the acceptable limit at 20 vehicles (50% of the highest limit) on a 40 ft. wide×100 ft. road segment); TRC_{dm}: cost of transporting 1 ton of HI d for a distance equivalent to one unit of time (we consider 30 minutes as one equivalent unit); $TRSC_{gm}$: cost of transporting 1 ton of resource g for a distance equivalent to one unit of time (we consider 30 minutes as one equivalent unit); FCE_i: fixed cost of opening an emergency handling center/fire station i to be used as a collection center; FC_j^w: fixed cost of opening distribution center j^w.

3.3 Formulation of the Model

Equations (1) and (2) determine relief operation support items and HI needed to be collected by the CNs for a successful relief operation. Constraints (3) and (4) ensure the provision of various resources and HI needed at the fire-affected locations based on population estimates obtained from city census records (resource requirements are based on a 100-person cluster needs, and the HI requirements are based on a 5-person family needs):

$$trs_g = \sum_{i \in I} y_{ig} \qquad \forall g \tag{1}$$

$$thr_d = \sum_{i \in I} x_{id} \qquad \forall d \tag{2}$$

$$trs_g \geq (1/100) \sum_{t \in T} po_{lt}\, pr_{g\,sc} \sum_{sc \in SC} PB_{sc} \qquad \forall l, g \tag{3}$$

$$thr_d \geq (1/5) \sum_{t \in T} po_{lt}\, pi_{d\,sc} \sum_{sc \in SC} PB_{sc} \qquad \forall l, d \tag{4}$$

Constraint (5) limits the collection of resources and HI at CNs based on their capacities. Equation (6) accounts for the total quantity of resources and HI at a CN. Equation (7) balances the flow of rescue and relief resources and HI from CN to TN against the outward flow on the route to the DCs around the fire-affected areas. Constraint (8) assigns a route when that route is found suitable by the monitoring team according to constraint (9). Constraint (10) estimates the response time based on the assigned route for the flow of relief items and the distance between the CN and the nearby TN according to the assigned route.

$$\sum_{g \in G} y_{ig} + \sum_{d \in D} x_{id} \leq CAP_i a_i \qquad \forall i \tag{5}$$

$$re_{idg} = x_{id} + y_{ig} \qquad \forall i,d,g \tag{6}$$

$$\sum_{i\in I} re_{idg} + \sum_{i\in I}\sum_{m\in M} flow_{ijgdm} = \sum_{j'\in J}\sum_{m\in M} flow_{jj'gdm} \qquad \forall g,d,j'=j+1 \tag{7}$$

$$flow_{ijgdm} \le ars_{ij}M \qquad \forall i,j,g,d,m \tag{8}$$

$$ars_{ij} \le su_{ij} \qquad \forall i,j \tag{9}$$

$$res_{ijm} = ars_{ij}CD_{ijm} \qquad \forall i,j,m \tag{10}$$

The emergency monitoring team checks the traffic density and suitability indices and assigns a route segment for transporting relief items according to the combined decision of constraints (11) and (12). The model decides if government intervention is needed, if an alternative route is to be selected, or if to continue on the existing route based on the combined decision of constraints (11) through (14). Equation (15) balances the flow between TNs, and constraint (16) balances the flow from TN to DCs and from there to HNs. Constraint (17) limits the flow of relief goods to DCs based on their capacities. Constraint (18) distributes relief items to HNs and makes sure that the quantity of relief material flows at the HNs inside the devastated area are balanced against the estimated required resource relief items.

$$ACC_{jj'} - TRD_{jj'} \le td_{jj'}M \qquad \forall j,j' \tag{11}$$

$$2ars_{jj'} \le su_{jj'} + td_{jj'} \qquad \forall j,j' \tag{12}$$

$$\sum_{j'\in J^t}\sum_{m\in\{1,4\}} flow_{jj'gdm} \le (1-ars_{jj'})M \qquad \forall j,j' \tag{13}$$

$$gv_{jj'} + atd_{jj'} \le (1-ars_{jj'})M \qquad \forall j,j' \tag{14}$$

$$\sum_{j'\in J^t}\sum_{m\in\{1,4\}} flow_{jj'gdm} = \sum_{j''\in J^t}\sum_{m\in\{1,4\}} flow_{j'j''gdm} \qquad \forall g,d \tag{15}$$

$$\sum_{j'\in J^w}\sum_{m=1,4} flow_{jj'gdm} = \sum_{j''\in H^d}\sum_{m=1,4} z_{j'j''gdm} \qquad \forall g,d \tag{16}$$

$$\sum_{j'\in J^w}\sum_{m=1,4} flow_{jj'gdm} \le v_{j^w}CPDC_{j^w gd} \qquad \forall g,d \tag{17}$$

$$\sum_{j^w\in J^w}\sum_{h^d\in H} z_{j^w h^d gd} = trs_g + thr_d \qquad \forall g,d \tag{18}$$

Equation (19) defines the response time between two neighboring TNs for the transportation mode used. The response time from a junction point to a DC is defined in equation (20), and that from a DC to an HN is defined in equation (21). Constraint (22) imposes integrality.

$$res_{jj'm} = dis_{jj'm} ars_{jj'} \quad \forall j, j'; j' > j, j \neq j' \tag{19}$$

$$res_{jj^w m} = dis_{jj^w m} ars_{jj^w} \qquad \forall j, j^w \tag{20}$$

$$res_{j^w h^d m} = dis_{j^w h^d m} ars_{j^w h^d} \qquad \forall j^w, h^d \tag{21}$$

$$a_i \in \{0,1\}, i \in I; v_{j^w} \in \{0,1\}, j^w \in J^w; gv_{jj'}, ars_{jj'}; atd_{jj}, td_{jj'} \in \{0,1\}, j, j' \in J; \tag{22}$$

Objective 1 defined in equation (23) minimizes the total response time *TRES*, which is defined in equation (24) considering the response time to send relief goods (resources and HI) from a CN to a nearby TN on a given transportation route, the time to send goods from one TN to the next, the time to send goods from a TN to a DC, and the time to transport goods from a DC to an HN in the affected areas. Objective (2) defined in equation (25) minimizes the total cost *TC*, which is defined in equation (26) as the sum of the procurement cost (*PRC*) and the logistics cost (*LGC*). *PRC* as defined in equation (26a) includes the collection costs of HI and resources for relief operation. *LGC* as defined in equation (26b) includes the cost of transporting relief goods to DCs and from there to demand points in the fire-affected areas; the fixed cost of opening collection centers; and the fixed cost of opening distribution centers around the fire-affected areas.

Objective 1: Minimize Response time *TRES* (23)

$$TRES = \sum_{i\in I}\sum_{j\in J}\sum_{m\in M} res_{ijm} + \sum_{j\in J}\sum_{\substack{j'\in J' \\ j<j'}} dis_{jj'm} + \sum_{j\in J}\sum_{j\in J^w} dis_{jj^w m} + \sum_{j^w\in J^w}\sum_{h^d\in H} dis_{j^w h^d m} \tag{24}$$

Objective 2: Minimize *TC* (25)

$$TC = PRC + LGC \tag{26}$$

$$PRC = \sum_{d\in D} CC_d thr_d + \sum_{g\in G} CR_g trs_g \tag{26a}$$

$$LGC = \sum_{m\in M} \left(\sum_{d\in D} TRC_{dm} thr_d + \sum_{g\in G} TRSC_{gm} tre_g\right)(CD_{ijm} + dis_{jj'm} + dis_{jj^w m} + DISTR_{j^w h^d m}) + \sum_{j^w\in J} FC_{j^w} v_{j^w} + \sum_{i\in I} FCE_i a_i \tag{26b}$$

4. NUMERICAL EXAMPLE

The research studied the map of Dhaka and chemical storage locations. By considering Dhaka's current road network, firefighting strategy, and fire stations, the study proposed 40 transit points (TNs) on the transportation routes of Dhaka, located at a reasonable distance of 15 to 30 minutes of transportation time for the delivery of relief items to hazard affected areas. Figure 1 in the Appendix presents a schematic map for the flow of relief items through the suggested transportation routes. On this map the CN positions are approximately at the points described in Subsection 2.1. The location of fire-affected area is shown on the map from a satellite-based picture provided by the BBC. The study also selected the locations for setting up 5 DCs around the hazard area, and 5 HNs as demand points to receive relief items. The proposed TNs, CNs, DCs and HNs (shown on the map as FAs for fire affected areas) are shown on network diagram prepared on a map used by the BBC for a report on the Dhaka fire disaster (We could not get any link to get the BBC's permission to use their map).

The study also proposed a disaster monitoring cell formed by Dhaka City Corporation which will become active when there is a fire or any other disaster. The cell may use a satellite enabled system to monitor the traffic density, traffic movement suitability on various routes considering road closures for any reason including accidents, and the physical road condition. The monitoring cell will continuously update the relief operations team on the suitability of a route segment for transportation of relief items based on traffic density and suitability indices defined in subsection 2.2.

4.1 Input Data

For minimizing the response time (Objective 1) for relief and rescue operations and for the mitigation of disaster situation, the model considered 6 CNs for the collection of required HI and resources and sending them to HNs as quickly as possible. The main sources of HI and resources include the Bangladesh Government (GOB), the city of Dhaka, NGOs, and foreign donations that are collected in warehouses in various cities including Dhaka, port cities of Chittagong, Khulna, and Narayanganj. From these warehouses the relief items will be transported to Dhaka by train, ships, and air. Foreign donations will mostly come through airports, river ports and sea ports. As such, the 6 CNs were positioned at the important city entry points into Dhaka as described earlier in Subsection 2.2. The model also considered 5 DCs, as discussed before, to receive relief items from the CNs and keep them in staged condition to be distributed to the HNs. We also assumed the collection costs of relief items and the truck-based transportation costs to account for the total costs (Objective 2). The HI and resources used as inputs including the estimation bases are shown in Table 1.

Table 1: Typical input data for humanitarian relief items (HI) and resources

Items	HI	Basis unit/ 5-person family	Support Resources	Basis unit/100 persons
1	Food	5pks/day	moveable container	1
2	Water	15 gallons/day	emergency cot	6
3	Medicine	1pk with all essentials/day	tent	6
4	Suitable Clothes	1pk with all essentials	ambulance	1
5	Baby Food	3pks/day (3 babies)	bulldozer	0.33
6	Safety Items	Shoes/wrapper	crane	0.25

4.2 Model Solutions

For response time the model considers the transportation times of the relief items along various possible routes originating at the 6 CNs, then moving through the TNs to reach the DCs, and finally from the DCs to the HNs. Table 2 presents typical example routes selected by the model and the corresponding response times. The response times presented here are the distances that are expressed in equivalent transportation times along the selected route segments.

Table2. Typical model output for response time in minutes for various transportation routes

Route from CN	Route details and corresponding time				Total time
CN 1: Route 1	CN1-TN11:40	TN11-TN40 :30	TN40-DC1:30	DC1-HN1:30	130
Route 2	CN1-TN13:30	TN13-TN39 :60	TN39-DC4:30	DC4-HN1:30	140
CN 2: Route 1	CN2-TN5:30	TN5-TN9:15	TN9-DC1:30	DC1-HN5:20	95
Route 2	CN2-TN5:30	TN5-TN7:60	TN7-DC3:30	DC3-HN2:40	160
CN3: Route 1	CN3-TN1: 15	TN1-TN7:80	TN7-DC3:30	DC3-HN2:40	165
Route 2	CN3-TN2: 30	TN2--TN8:30	TN8-DC3:30	DC3-HN2:40	130

Considering all the optimum routes for supplying HI and resources from the 6 CNs to the 5-disaster affected HNs, the optimal Objective 1 value is 6420 minutes, or 107 hours. However, since these routes are working in parallel, the response time is equivalent to only one of the routes. The model considered 16 routes based on the minimum-time route options from the CNs to the HNs. As such, the response time is 107/16=7 hours on average. Based on the Dhaka city map the longest distance is from c4 (Figure 1 in the appendix) which is the assumed location for the CN at the Dhaka Airport Road entry point. The optimal Objective 2 (total cost) is $13.55 million that includes the procurement cost of $7.3 million and the logistics cost of $6.25 million. The procurement cost applies to the resources and HI items as shown Table1.

5. REASONS FOR DHAKA FIRE AND STEPS TAKEN BY THE GOVERNMENT

The old part of Dhaka (that includes Chawkbazar fire-disaster area) houses more than 87 warehouses (Nimtoli to Chawkbazar, 2019) for chemicals used in industries. Some of these chemicals are flammable. According to the Fire Service and Civil Defense authority, generating awareness among people is very important so that they do not allow any chemical storage/ warehouse in their area. After the Nimtoli disaster in April 2011(Nimtoli to Chawkbazar, 2019), the government decided to shift all chemical warehouses from residential areas to industrial zones in Keraniganj, by introducing a US$252.3M project called “Chemical Shilpa Nagar”. The project, to be implemented on a 50-acre land, is scheduled to be completed in June 2021.

A similar situation to the Dhaka fire was reported by Shook (1997) in which fire broke out in a chemical storage facility at the Klong Toey Port of Bangkok, Thailand. The Port Authority firefighters used water, the traditional fire suppression material, but they failed to extinguish the fire. The fire killed 7 people and exposed another 50,000 to 60,000 to toxic fumes of methylene bromide and other hazardous chemicals. The Thai government thoroughly studied the risks and vulnerabilities by involving experts and the affected people and implemented measures to improve the handling of chemicals and firefighting practices. Dhaka could learn lessons from Bangkok on chemical storage control and implementation.

6. CONCLUSIONS

The proposed research contributed to the HL planning literature by developing a model-based approach for optimizing disaster response time to initiate relief operations in a densely populated city facing a fire-based humanitarian crisis. The research introduced traffic density and suitability indices for expediting the transportation of relief items. A novel feature of the model formulation is to allow for government intervention when the traffic density, suitability indices, and the alternative routes provision cannot be applied. The model supports the relief operations team to pinpoint the problem(s) causing relief flow hindrance in the logistics network, and to find a solution.

The research considered the schematic map of Dhaka, and the actual location of the occurrence of the fire incident that recently devastated the old part of the city. The proposed model and the overall approach may be applied in similar situations.

7. REFERENCES

Apte, A. (2009). Humanitarian logistics: A new field of research and action, Foundations and Trends® in Technology. *Information and Operations Management* 3(1), 1–100.

Apte, A., Khawam, J., Reginer, E., Simon J. (2016). Complexity and self-sustainment in disaster response supply chains. *Decision Sciences*, 47(6), 998-1015.

Arnette, A.N., Zobel, C.W. (2019). A Risk-Based Approach to Improving Disaster Relief Asset Pre-Positioning. *Production and Operations Management*, 28(2), 457-478.

CRED (2018) Advanced Search, Université Catholique de Louvain, Brussels, available at: www.emdat.be/advanced_search/index.html

Himota, K., Tanaka, T. (2008). Development and validation of a physics-based urban fire spread model. *Fire Safety Journal* 43, 477-494.

Himota, K., Tanaka, T. (2012). A model for the fire-fighting activity of local residents in urban fires. *Fire Safety Journal* 54, 155-166.

Jain, S., McLean, C. (2008). Components of an incident management simulation and gaming framework and related developments. *Simulation* 84(1), 3–25.

Jones, E. (2013). Director of American Red Cross Regional Disaster Services Presentation. Presentation made at the Second Mini-conference in Humanitarian Operations and Crisis Management, POMS College of Humanitarian Operations and Crisis Management, Denver, CO.

Nimtoli to Chawkbazar (2019). Daily Star Report : https://www.thedailystar.net/frontpage/news/dhaka-fire-nimtoli-chawkbazar-lesson-not-learnt-1705771.

Navitas, P. (2014). Improving Resilience against Urban Fire Hazards through Environmental Design in Dense Urban Areas in Surabaya, Indonesia, *Procedia - Social and Behavioral Sciences* 135 (2014) 178 – 183.

Shook, G. (1997). An assessment of disaster risk and its management in Thailand. *Disasters* 21(1),77-88

Vanajakumari, M., Kumar, S., Gupta, S. (2016). An integrated logistics model for predictable disasters. *Production and Operations Management* 25(5), 791-811

Wagner, N., Agarwal, V. (2014). An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster, *Expert Systems with Applications*, 41(2014), 2807-2815.

Waheed, M. A.A. (2014). Approach to fire-related disaster management in high-density urban areas, *Fourth International Symposium on Infrastructure Engineering in Developing Countries*, IEDC, 2013, published in Procedia Engineering 77(2014), 61-69.

APPENDIX

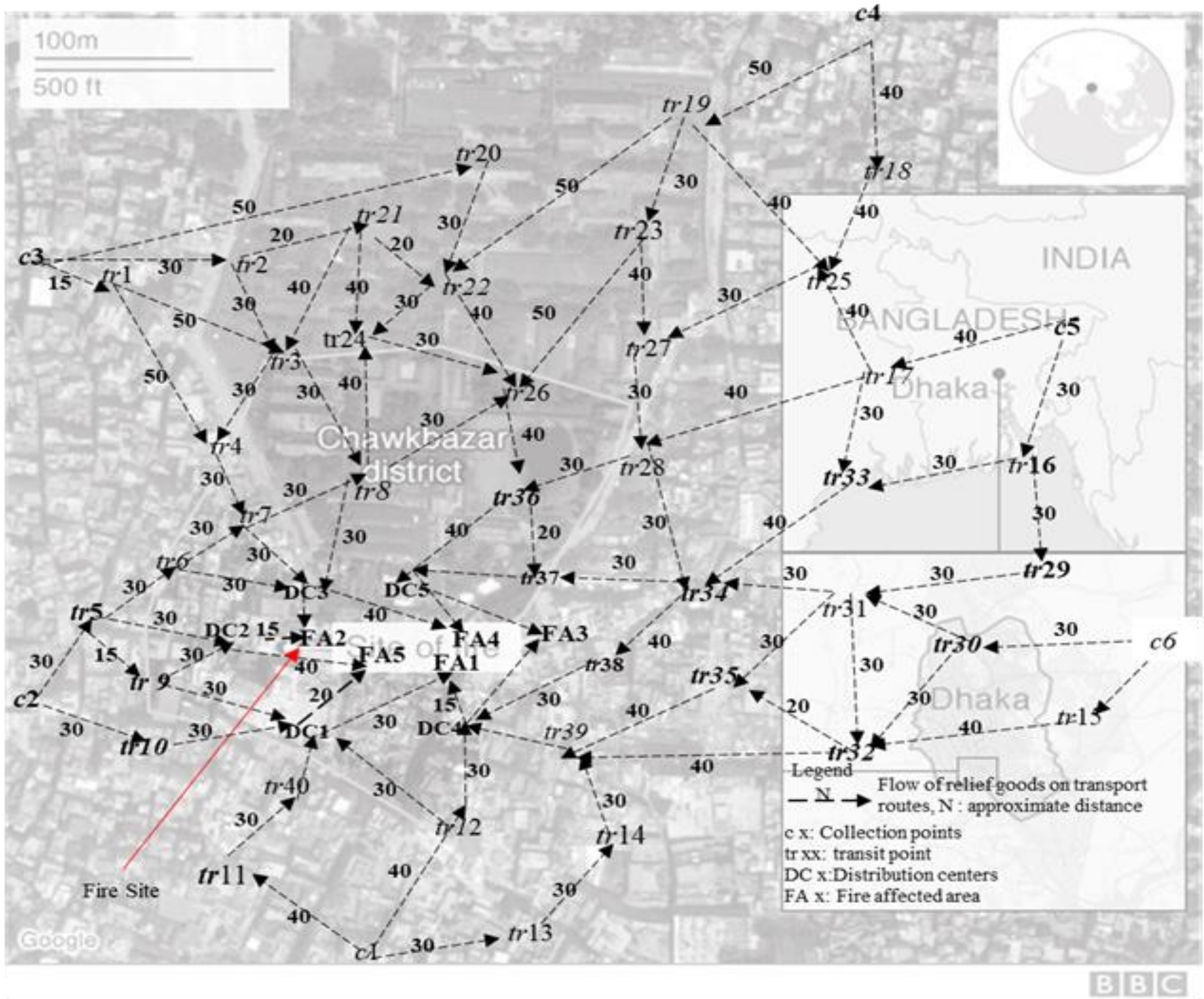

Figure 1. Schematic map of Dhaka and the proposed transportation routes for the relief operation