Applying linear programming for logistics distribution of essential relief items during COVID-19 lockdown: evidence from Bangladesh

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Abstract: COVID-19 induced lockdowns have made it extremely difficult for the poorer section of the community to arrange sustenance items like food and medicines due to the lack of cash flow coupled with the closure of markets. Although multiple organisations took initiatives to help this vulnerable cohort by distributing essential items, they ended up either oversupplying or undersupplying at different regions due to the lack of a reference framework. Hence, the study develops a model to aid the national relief distribution process during a pandemic. This study considers the capacitated plant location model and applies the linear programming tool to formulate and solve the model. The model assigns a target and service zones, to relief organisations based on their capacity and proximity and avoid redundant relief goods to easily accessible areas. The model can be used by government, private, and non-profit alike to distribute relief during any similar future events as well.

Keywords: COVID-19; pandemic; essential items; relief distribution; capacitated plant location model; linear programming; Bangladesh.

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1 Introduction

The global outbreak of COVID-19 has caused major disruptions in practically all fields of business and human lives (Queiroz et al., 2020; Allahi et al., 2021). The pandemic has created a significant mismatch between supply and demand, primarily due to the lack of availability of essential items like food, grocery, and pharmaceutical products (Kumar et al., 2020). The lack of receiving essential goods during this period has been further compounded by multiple lockdowns that have affected people from all strata of life, but especially the population below the poverty line and informal floating workers (Alam et al., 2021).

In the face of this global pandemic, and to create a sustainable society, it has become extremely important to ensure the availability of essential items for poor people (van Barneveld et al., 2020). In this context, logistics plays an important role in the efficient distribution of relief items (Kovács and Falagara Sigala, 2021). Sokat and Altay (2020), in their recently conducted review on humanitarian logistics, have highlighted the need for serving vulnerable populations during an epidemic or pandemic. In this context, logistics, which can be stated as the process of moving goods from the point of origin to the point of consumption, has been observed to play a significant role in the success of relief operations. Further, proper logistics distribution design is needed for the distribution of essential relief items.

Babatunde et al. (2020), in their review about the distribution of medical and healthcare products in Africa, has highlighted the importance of logistics models in the distribution of healthcare commodities for emergencies in Africa. In a similar vein, the current study also focuses on developing a model with particular attention on minimising the transportation cost as well as the total cost of the project. The current study intends to aid the decision-makers in serving the most vulnerable population impacted by the COVID-19 pandemic through the limited budget of different NGOs of Bangladesh. This study intends to develop a model for logistics distribution of essential items relief to serve the needy individuals of Bangladesh. The objective of the developed model is to distribute essential items among poor individuals with the help of a small, medium, and large NGOs at a minimised cost. The study selects less economically developed areas of Bangladesh that are more impacted by the pandemic-induced lockdowns and develops a logistics model to distribute essential relief items to those areas. The study also considers the selected areas as demand points and includes different types of NGOs as the sources. A cost matrix is developed considering the distance of the selected demand areas and a sample logistics fare rate. Finally, the developed model is solved to get a minimum cost to distribute essential reliefs with the help of different NGOs of Bangladesh.

The paper is structured as follows. Beginning with the review of the extant literature in the domain of humanitarian logistics and operations during the pandemic, the paper goes on to discuss the theoretical background behind the study. The sections devoted to formulating and implementing the models follow the theoretical background, and the results are drawn and exhibited from the analysis. Next, the theoretical and practical implications are discussed. Finally, concluding remarks of this research work are provided. The government or regulatory body can use this distribution model to collaborate among NGOs, thereby distributing the relief items at a lower cost.

2 Literature review

In the past couple of decades, a plethora of catastrophic natural and manmade disasters have resulted in millions of deaths and billions of dollars of economic loss. As a result, logistics distribution of humanitarian relief (essential items) distribution has attracted the attention of academic researchers worldwide. Previous research indicated that food ration and essential relief packages (and relief kits) for vulnerable communities in Bangladesh during lockdown contained rice, wheat flour, pulses, cooking oil, salt, vegetables, and soap/detergent powder. The content in the relief package is suitable for the consumption of local people and can sustain a family of five members for two weeks. To serve the right items to the locals, it is important to first assess the community needs and then buy the right quality of items at a competitive price., Finally, the distribution must be done carefully in the corona-affected areas by following the government-issued COVID-19 guidelines. These relief packages are expected to save many struggling families and older people in quarantined cities (Shammi et al., 2021).

Humanitarian relief logistics (HRL) is one of the most critical elements of a relief operation in disaster management. HRL can be stated as the systems and processes comprising various resources that might serve in aiding the vulnerable population who are seriously affected by catastrophic situations and require help (Budak et al., 2020; Lu et al., 2016). HRL is a critical factor in managing relief operations. Due to the increasing number of natural and man-made disasters, a key strategic issue for humanitarian logistics is to ensure adequate capacity and resources that enable efficient relief operations (Liberatore et al., 2014) in pre-disaster (Ichoua, 2010) and post-disaster (Marcelin et al., 2016; Ransikarbum and Mason, 2016a; Sheu, 2014) planning (Boostani et al., 2020; Lu et al., 2016).

The distribution of emergency goods to a population affected by a disaster is one of the most fundamental operations in humanitarian logistics (Sheu and Kundu, 2018, Tofighi et al., 2016). Hence, the facility location problem has become the preferred approach for dealing with emergency humanitarian logistical problems (Boonmee et al., 2017). In general, there has been a lack of attention on developing mathematical models and solution algorithms for strategic and tactical decisions in this area. Nevertheless, multiple models have been developed for the logistics distribution of humanitarian relief (Cheng et al., 2021; Zhang and Cui, 2021). Most of the models focused on minimising the total cost of logistics distribution and providing availability of relief goods (e.g., Boonmee et al., 2017; Zhen et al., 2015; etc.). A comprehensive bibliographic analysis of HRL can be found in Bag (2016). In a recent study, Bag et al. (2020) analyses the barriers of big data analytics in sustainable HRL; and Modgil et al. (2020) identify the enablers, challenges, and theoretical developments of quality management practices in relief operations. Existing HRL literature includes the application of linear (Alizade and Hassanzadeh, 2020), nonlinear (Cao et al., 2018; Wang et al., 2014), integer (Zhen et al., 2015), multi-criteria (Rekik et al., 2013; Safaei et al., 2018), multi-objectives (Abounacer et al., 2014; Ransikarbum and Mason, 2016b), bi-level (Safaei et al., 2018) and stochastic (Alem et al., 2016; Tofighi et al., 2016; Zahiri et al., 2017) programming. Besides these exact methods, applications of heuristic models such as genetic algorithm (Cao et al., 2018), ant colony optimisation (Yi and Kumar, 2007), Lagrangean relaxation (Nassief et al., 2016), etc. are also found in relief logistics (Barzinpour et al., 2014; Hadas and Laor, 2013).

Researchers attempted to develop a logistics model under catastrophic situations such as an earthquake (Ahmadi et al., 2015; Fikar et al., 2018; Lu et al., 2016; Sheu, 2014), hurricanes (Marcelin et al., 2016), terrorist attacks (Hadas and Laor, 2013), etc. Recently, considering the COVID outbreak and subsequent lockdowns, Singh et al. (2021) developed a resilient and responsive food supply chain and vehicle rerouting decisions. Choi (2020) introduced a mobile service operations mechanism to tackle logistics disruption. In the context of COVID-19, applications of big data analytics to strengthen the resiliency of healthcare and manufacturing supply chains can be found in Bag et al. (2021a, 2021b). However, the above-mentioned literature did not focus on relief logistics. Thus, it can be stated that most of the prior studies were aimed at designing distribution networks focusing on humanitarian logistics, logistics distribution, relief distribution, and relief logistics. However, as observed from reviewing the extant literature, there is still a significant dearth of studies focusing on the distribution of essential relief items during a pandemic. The current study intends to shed some light on this important but sparsely discussed issue, which is essential for developing countries like Bangladesh by designing a distribution network for essential relief items.

3 Emergency relief logistics model

In the current study, a capacitated plant location model is considered to distribute emergency reliefs from various sources to demand points. The model considers NGOs as the source points and needy regions as the demand points. Each source has a limited supply of relief as per its capacity. The needy regions are greatly affected by the COVID lockdown, thereby requiring a certain amount of emergency relief for the poor people residing in the region. The model harbours the following assumptions,

m number of potential sources (NGOs)

n number of demand points

K_i available capacity of source i where $i = 1, \ldots, m$

D_j demand for reliefs at location j where $j = 1, \ldots, n$

c_{ij} logistics cost per truckload from source i to demand point j

x_{ij} relief quantity shipped from source i to demand point j.

Therefore, the total logistics cost is $\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}X_{ij}$. Thus, the problem can be formulated as

Objective function:

$$Min \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}X_{ij} \tag{1}$$

Subject to,

$$\sum_{i=1}^{m} X_{ij} = D_j \tag{2}$$

$$\sum_{j=1}^{n} X_{ij} \le K_i \tag{3}$$

$$\sum_{j=1}^{n} D_j \le \sum_{i=1}^{m} K_i \tag{4}$$

where $i = 1, \ldots, m$ and $j = 1, \ldots, n$.

Equation (1) represents the problem as a cost-minimisation problem. The constraints ensure that the demand at any location is met from various sources [equation (2)], the total shipment from a source does not exceed its capacity [equation (3)], and the total demand is less than or equal to the total available supply [equation (4)]. In case of a shortage of supplies, a portion of the original demand can be considered to be fulfilled.

4 Implementing the model through an illustrative example

In Bangladesh, relief activities are coordinated by the government with the help of administrative units. The administration of Bangladesh has 8 divisions, 64 districts, and 577 sub-districts (including 492 upazilas and 45 metropolitan thanas) (BBS, 2020). The authors consider the sub-districts with the highest poverty headcount ratio (HCR) in each division as demand points since COVID-19 has badly hit these areas, and in turn, severely affected the poor people living in these regions Additionally, it was also observed that the selected demand locations have a poverty HCR more than 50% (BBS, 2020). Thus, the number of populations below the poverty line can therefore be estimated from the total population data and the corresponding poverty HCR of the location. Assuming one relief package for each of the 'poor' individuals, the demand for relief packages can be calculated. For logistics convenience, the demand can be expressed in terms of the required numbers of full truckloads where each truck weighs 10 tons and carries 1,000 ten-kg packages. This is exhibited in Table 1.

Table 1 Demands for COVID essential reliefs at selected regions in the country

	Division	*Subdistrict (i.e., Upazila) with the highest poverty headcount*	*Population in the Upazila*	*Poverty headcount ratio (%)*	*Demand (10-ton-truckload; 1,000 packages)*
Demand1	Barisal	Dashmina, Patuakhali	123,388	52.8	66
Demand2	Chattogram	Thanchi, Bandarban	23,591	77.8	19
Demand3	Dhaka	Mithamain, Kishoregonj	122,026	61.3	75
Demand4	Khulna	Mohammadpur, Magura	207,905	62.4	130
Demand5	Mymensingh	Dewanganj, Jamalpur	258,133	63.2	164
Demand6	Rajshahi	Porsha, Naogaon	132,095	48.7	65
Demand7	Rangpur	Char Rajibpur, Kurigram	73,373	79.8	59
Demand8	Sylhet	Sulla, Sunamganj	113,743	60.9	70

The study considers several NGOs as the source points throughout the country, located at each of the eight divisional districts. In real life, NGOs have varying capacities based on their available fund, logistics resources, national and international networking, etc. To present a comprehensive example, the authors considered three levels of capacities (i.e., large, medium, and small). Additionally, the authors also assumed that NGOs located in bigger cities such as Dhaka, Chittagong, and Rajshahi have a larger capacity of 120,000 packages, NGOs located in Sylhet and Khulna have a medium capacity of 80,000 packages, and NGOs located in Barisal, Rangpur, and Mymensingh have a smaller capacity of 60,000 packages. This is provided in Table 2.

Table 2 Capacities of the source points

Sources	*Location (divisional district)*	*Assumed capacity (10-ton-truckload; 1,000 packages)*
NGO1	Barisal	60
NGO2	Chattogram	120
NGO3	Dhaka	120
NGO4	Khulna	80
NGO5	Mymensingh	60
NGO6	Rajshahi	120
NGO7	Rangpur	60
NGO8	Sylhet	80

Next, the pairwise distances from each source point to each demand point with the help of a Google Map are determined and provided in Table 3.

Table 3 Pairwise distance (km) between source and demand points

Location	*Dashmina, Patuakhali*	*Thanchi, Bandarban*	*Mithamain, Kishoregonj*	*Mohammadpur, Magura*
Barisal	73.1	376	500	158
Chattogram	299	137	481	383
Dhaka	310	382	350	149
Khulna	183	485	532	94.1
Mymensingh	397	494	178	235
Rajshahi	411	629	416	213
Rangpur	551	684	470	353
Sylhet	485	510	152	377
Location	*Dewanganj, Jamalpur*	*Porsha, Naogaon*	*Char Rajibpur, Kurigram*	*Sulla, Sunamganj*
Barisal	372	439	410	472
Chattogram	453	540	491	453
Dhaka	209	296	247	322
Khulna	410	367	448	504
Mymensingh	98.6	286	131	150
Rajshahi	267	100	305	388
Rangpur	321	162	359	442
Sylhet	379	505	401	124

The next step comprised determining the cost of shipment based on the distance. In Bangladesh, a 10-ton-truckload typically costs between Bangladesh Taka (BDT) 5,000 to 10,000 based on the distance to be covered. To effectively model the shipment fare, the model assumes a basic fare of BDT 5,000 for the first 100 km distance, and subsequently, an added BDT 1,000 for each of the next 100 km distances (Table 4). The maximum fare is assumed to be BDT 10,000. For example, if the distance between point A and point B is 300 km, the logistics cost would be BDT 7,000 (= 5,000 + 100 * 2). Therefore, the logistics cost estimate among the source and demand points is calculated (Table 5). It will be worthwhile to mention here that the sample fare rate may differ for a particular company and eventually the logistics costs from sources to demand points may be adjusted. In some cases, the logistics agreement may be influenced by the buying power of the customer and the availability of logistics providers.

Table 4 A sample logistics fare estimates for a ten-ton truckload in Bangladesh

KM	<100	100–199	200–299	300–399	400–499	500+
Fare (BDT)	5,000	6,000	7,000	8,000	9,000	10,000

Table 5 Logistics costs (BDT) for a ten-ton truckload from sources to demand points

Location	*Dashmina, Patuakhali*	*Thanchi, Bandarban*	*Mithamain, Kishoregonj*	*Mohammadpur, Magura*
Barisal	5,000	8,000	10,000	6,000
Chattogram	7,000	6,000	9,000	8,000
Dhaka	8,000	8,000	8,000	6,000
Khulna	6,000	9,000	10,000	5,000
Mymensingh	8,000	9,000	6,000	7,000
Rajshahi	9,000	10,000	9,000	7,000
Rangpur	10,000	10,000	9,000	8,000
Sylhet	9,000	10,000	6,000	8,000
Location	*Dewanganj, Jamalpur*	*Porsha, Naogaon*	*Char Rajibpur, Kurigram*	*Sulla, Sunamganj*
Barisal	8,000	9,000	9,000	9,000
Chattogram	9,000	10,000	9,000	9,000
Dhaka	7,000	7,000	7,000	8,000
Khulna	9,000	8,000	9,000	10,000
Mymensingh	5,000	7,000	6,000	6,000
Rajshahi	7,000	6,000	8,000	8,000
Rangpur	8,000	6,000	8,000	9,000
Sylhet	8,000	10,000	9,000	6,000

Finally, considering the shipped quantity (x_{ij}) as decision variables, an excel solver was used to find the optimal solution following the Simplex LP method. The current model comprised 68 decision variables and 17 constraints. The solver found a globally optimal solution satisfying all constraints and optimality conditions with a minimum total logistics cost of BDT 4,030,000. Table 6 shows the optimal relief shipments to various demand points. For example, Demand7 (i.e., Char Rajibpur, Kurigram) needs 59 truckloads of reliefs that NGO3 solely fulfils, whereas Demand5 (i.e., Dewanganj, Jamalpur) needs 164 truckloads that are fulfilled by the collective supports from NGO3, NGO5, and NGO6. These are provided to the readers in Table 6.

Table 6 Optimised relief shipment between the source and demand points

		[Logistics unit = 10-ton-truckload; 1,000 packages]							
Demand points		*Demand1*	*Demand2*	*Demand3*	*Demand4*	*Demand5*	*Demand6*	*Demand7*	*Demand8*
Sources	*Used capacity* / *Fulfilled demand = 648*	*66*	*19*	*75*	*130*	*164*	*65*	*59*	*70*
NGO1	*60*	60	0	0	0	0	0	0	0
NGO2	*68*	6	19	43	0	0	0	0	0
NGO3	*120*	0	0	0	50	11	0	59	0
NGO4	*80*	0	0	0	80	0	0	0	0
NGO5	*60*	0	0	22	0	38	0	0	0
NGO6	*120*	0	0	0	0	115	5	0	0
NGO7	*60*	0	0	0	0	0	60	0	0
NGO8	*80*	0	0	10	0	0	0	0	70

5 Discussion

5.1 Theoretical implications

The study extends the application of linear programming in distributing essential relief items by the administrative authorities and NGOs in Bangladesh under a lockdown scenario. The demand is conjectured from the poverty HCR and the corresponding population in the region, while the source capacity is assumed based on the economic size of the divisional region. Even though the logistics cost of carrying reliefs is nonlinear (i.e., stepwise), it can be linearly approximated by assuming a full truckload as the logistics unit.

The current study also proposes a model to distribute essential items relief among COVID-19 lockdown affected poor people in Bangladesh. This model aims at minimising the total logistics cost. Here, the study assumes that several NGOs of Bangladesh contribute to providing essential items such as food grains among the COVID-19 lockdown affected poor people. The study uses linear programming to coordinate the overall distribution. Literature indicates that although multiple studies have been recently published on COVID-19 in context to Bangladesh (Amjath-Babu et al., 2020; Shammi et al., 2020, 2021; Kundu et al., 2021; Kabir et al., 2021), but there is a dearth of studies on assessment on supply and demand positions of ration and essential items relief supply among vulnerable communities. The current study, through proposing the novel model, advances the literature on the relief supply chain.

5.2 Practical implications

As an illustrative case example, the study considers eight demand points and eight sources to formulate the model and obtain a minimised cost of BDT 4.03 million to distribute 648,000 relief packages to the selected areas. Here, the demand points are located at the sub-district level with a higher poverty HCR, and the sources are located at the divisional districts. On a large-scale implementation by the government, unlike considering only one demand point (with the highest poverty headcount) and one source point in each division, all 64 districts and 577 sub-districts can be considered as the sources and demand points, respectively. In case of a shortage of funds or available supplies, locations that belong to high poverty severity groups can be considered as demand points.

The government office (e.g., the Ministry of Disaster Management and Relief, the Department of Social Service, NGO Affairs Bureau, etc.) may keep a comprehensive database of the lockdown affected people and allocate their necessities to be fulfilled by listed non-profit organisations and corporate social responsibility (CSR) activities. During calamities and pandemics, several organisations compete with each other in serving accessible areas in close proximities with similar reliefs. In many cases, there are duplications of beneficiaries, and more importantly, the deprivation of needy people in far regions. In the current model, the needs of the people are considered as demands, and potential reliefs from non-profit organisations and CSR activities are considered as sources. Thus, the proposed model coordinates the combined efforts of the government, NGO, and CSR activities to fulfil the needs of emergency items relief, and is expected to be implemented to coordinate the essential relief logistics system during the COVID-19 lockdown.

6 Conclusions

The primary objective of the study was to formulate a linear programming model to allocate essential items such as food supplies among poor people at a low cost. Areas with a higher poverty headcount are considered as the demand points. Some NGOs are considered as the source points. The authors assume the relief sources are located at the divisional district, whereas the demand for reliefs is more severe at the sub-districts with a higher poverty HCR within the division. Linear programming is used to formulate the model to find out the minimum logistics cost to distribute essential relief items during the COVID-19 lockdown. The current study aims to develop a model that aids in the coordination between the government and non-government organisations concerning distributing essential items among the impoverished group at a minimal cost. Since NGOs have different types of projects, cost becomes a highly crucial factor. Considering this factor, the authors design a logistics distribution model for allotting essential items at a minimised cost.

Like most research studies, the current study is not devoid of its limitations. There are some limitations in the work that can be improved and extended in future research activities. The proposed model serves essential items to selected demand points based on the poverty HCR. If the capacities of the NGOs are increased or additional NGOs are considered, then the number of areas that can be served can be significantly increased. Moreover, each divisional region may host multiple NGOs with varying capacities, where larger relief organisations could be allocated to the less developed areas. In collaboration with the National Board of Revenue, tax incentives and rebates may be offered to increase the available supplies of reliefs. A further extension of the proposed model can be leveraged if a comprehensive registry of all peoples below the poverty line is maintained, and thereby obtaining an accurate record of essential needs of people during lockdown can be assessed properly. Furthermore, the model assumes direct shipments from sources to demand points. However, as a future research activity, distribution centres can be added between sources and demand points. Other types of distribution networks (e.g., milk-run, cross-docking, hub, spoke, etc.) can also be considered for the relief logistics system, thereby paving the way for future research avenues.

References

Abounacer, R., Rekik, M. and Renaud, J. (2014) 'An exact solution approach for multi-objective location-transportation problem for disaster response', *Computers and Operations Research*, Vol. 41, No. 1, pp.83–93 [online] https://doi.org/10.1016/j.cor.2013.08.001.

Ahmadi, M., Seifi, A. and Tootooni, B. (2015) 'A humanitarian logistics model for disaster relief operation considering network failure and standard relief time: a case study on San Francisco district', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 75, pp.145–163 [online] https://doi.org/10.1016/j.tre.2015.01.008.

Alam, S., Adnan, Z.H., Baten, M.A. and Bag, S. (2021) 'Assessing vulnerability of informal floating workers in Bangladesh before and during COVID-19 pandemic: a multi-method analysis', *Benchmarking: An International Journal* [online] https://doi.org/10.1108/BIJ-06-2021-0329.

Alem, D., Clark, A. and Moreno, A. (2016) 'Stochastic network models for logistics planning in disaster relief', *European Journal of Operational Research*, Vol. 255, No. 1, pp.187–206 [online] https://doi.org/10.1016/j.ejor.2016.04.041.

Alizade, S. and Hassanzadeh, R. (2020) 'Modeling and solving the problem of locating bi-objective allocation in humanitarian logistics with regard to urban infrastructure', *Journal of Emergency Management*, Vol. 9, No. 2, pp.33–43.

Allahi, F., Fateh, A., Revetria, R. and Cianci, R. (2021) 'The COVID-19 epidemic and evaluating the corresponding responses to crisis management in refugees: a system dynamic approach', *Journal of Humanitarian Logistics and Supply Chain Management* [online] https://doi.org/10.1108/JHLSCM-09-2020-0077.

Amjath-Babu, T.S., Krupnik, T.J., Thilsted, S.H. and McDonald, A.J. (2020) 'Key indicators for monitoring food system disruptions caused by the COVID-19 pandemic: insights from Bangladesh towards effective response', *Food Security*, Vol. 12, No. 4, pp.761–768.

Babatunde, S., Oloruntoba, R. and Agho, K. (2020) 'Healthcare commodities for emergencies in Africa: review of logistics models, suggested model and research agenda', *Journal of Humanitarian Logistics and Supply Chain Management*, Vol. 10, No. 3, pp.371–390 [online] https://doi.org/10.1108/JHLSCM-09-2019-0064.

Bag, S. (2016) 'Humanitarian supply chain management: a bibliometric analysis of the literature', *AIMS International Journal of Management*, Vol. 10, No. 3, pp.175–202.

Bag, S., Dhamija, P., Luthra, S. and Huisingh, D. (2021a) 'How big data analytics can help manufacturing companies strengthen supply chain resilience in the context of the COVID-19 pandemic', *The International Journal of Logistics Management* [online] https://doi.org/10.1108/IJLM-02-2021-0095.

Bag, S., Gupta, S., Choi, T.M. and Kumar, A. (2021b) 'Roles of innovation leadership on using big data analytics to establish resilient healthcare supply chains to combat the COVID-19 pandemic: a multimethodological study', *IEEE Transactions on Engineering Management* [online] https://doi.org/10.1109/TEM.2021.3101590.

Bag, S., Gupta, S. and Wood, L. (2020) 'Big data analytics in sustainable humanitarian supply chain: Barriers and their interactions', *Annals of Operations Research*, pp.1–40 [online] https://doi.org/10.1007/s10479-020-03790-7.

Barzinpour, F., Saffarian, M., Makoui, A. and Teimoury, E. (2014) 'Metaheuristic algorithm for solving biobjective possibility planning model of location-allocation in disaster relief logistics', *Journal of Applied Mathematics* [online] https://doi.org/10.1155/2014/239868.

BBS (2020) *Poverty Maps of Bangladesh 2016*, Bangladesh Bureau of Statistics, ISBN: 978-984-34-9773-4.

Boonmee, C., Arimura, M. and Asada, T. (2017) 'Facility location optimization model for emergency humanitarian logistics', *International Journal of Disaster Risk Reduction*, June, Vol. 24, pp.485–498 [online] https://doi.org/10.1016/j.ijdrr.2017.01.017.

Boostani, A., Jolai, F. and Bozorgi-Amiri, A. (2020) 'Designing a sustainable humanitarian relief logistics model in pre-and postdisaster management', *International Journal of Sustainable Transportation*, Vol. 15, No. 8, pp.604–620.

Budak, A., Kaya, İ., Karaşan, A. and Erdoğan, M. (2020) 'Real-time location systems selection by using a fuzzy MCDM approach: an application in humanitarian relief logistics', *Applied Soft Computing*, Vol. 92, p.106322 [online] https://doi.org/10.1016/j.asoc.2020.106322.

Cao, C., Li, C., Yang, Q., Liu, Y. and Qu, T. (2018) 'A novel multi-objective programming model of relief distribution for sustainable disaster supply chain in large-scale natural disasters', *Journal of Cleaner Production*, Vol. 174, pp.1422–1435 [online] https://doi.org/10.1016/j.jclepro.2017.11.037.

Cheng, J., Feng, X. and Bai, X. (2021) 'Modeling equitable and effective distribution problem in humanitarian relief logistics by robust goal programming', *Computers & Industrial Engineering*, Vol. 155, Article no. 107183, https://doi.org/10.1016/j.cie.2021.107183.

Choi, T.M. (2020) 'Innovative 'bring-service-near-your-home' operations under corona-virus (COVID-19/SARS-CoV-2) outbreak: can logistics become the messiah?', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 140, p.101961, https://doi.org/10.1016/j.tre.2020.101961.

Fikar, C., Hirsch, P. and Nolz, P.C. (2018) 'Agent-based simulation optimization for dynamic disaster relief distribution', *Central European Journal of Operations Research*, Vol. 26, No. 2, pp.423–442 [online] https://doi.org/10.1007/s10100-017-0518-3.

Hadas, Y. and Laor, A. (2013) 'Network design model with evacuation constraints', *Transportation Research Part A: Policy and Practice*, Vol. 47, pp.1–9 [online] https://doi.org/10.1016/j.tra.2012.10.027.

Ichoua, S. (2010) 'Humanitarian logistics network design for an effective disaster response', *Proceedings of the 7th International ISCRAM Conference*, Seattle, pp.1–4 [online] https://doi.org/10.1080/09614520903564322.

Kabir, H., Maple, M. and Usher, K. (2021) 'The impact of COVID-19 on Bangladeshi readymade garment (RMG) workers', *Journal of Public Health*, Vol. 43, No. 1, pp.47–52.

Kovács, G. and Falagara Sigala, I. (2021) 'Lessons learned from humanitarian logistics to manage supply chain disruptions', *Journal of Supply Chain Management*, Vol. 57, No. 1, pp.41–49 [online] https://doi.org/10.1111/jscm.12253.

Kumar, A., Luthra, S., Mangla, S.K. and Kazançoğlu, Y. (2020) 'COVID-19 impact on sustainable production and operations management', *Sustainable Operations and Computers*, Vol. 1, pp.1–7, https://doi.org/10.1016/j.susoc.2020.06.001.

Kundu, S., Al Banna, M.H., Sayeed, A., Sultana, M.S., Brazendale, K., Harris, J. and Khan, M.S.I. (2021) 'Determinants of household food security and dietary diversity during the COVID-19 pandemic in Bangladesh', *Public Health Nutrition*, Vol. 24, No. 5, pp.1079–1087.

Liberatore, F., Ortuño, M.T., Tirado, G., Vitoriano, B. and Scaparra, M.P. (2014) 'A hierarchical compromise model for the joint optimization of recovery operations and distribution of emergency goods in humanitarian logistics', *Computers and Operations Research*, Vol. 42, pp.3–13 [online] https://doi.org/10.1016/j.cor.2012.03.019.

Lu, C.C., Ying, K.C. and Chen, H.J. (2016) 'Real-time relief distribution in the aftermath of disasters – a rolling horizon approach', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 93, pp.1–20 [online] https://doi.org/10.1016/j.tre.2016.05.002.

Marcelin, J.M., Horner, M.W., Ozguven, E.E. and Kocatepe, A. (2016) 'How does accessibility to post-disaster relief compare between the aging and the general population? A spatial network optimization analysis of hurricane relief facility locations', *International Journal of Disaster Risk Reduction*, Vol. 15, pp.61–72 [online] https://doi.org/10.1016/j.ijdrr.2015.12.006.

Modgil, S., Singh, R.K. and Foropon, C. (2020) 'Quality management in humanitarian operations and disaster relief management: a review and future research directions', *Annals of Operations Research*, pp.1–54 [online] https://doi.org/10.1007/s10479-020-03695-5.

Nassief, W., Contreras, I. and Asad, R. (2016) 'A mixed-integer programming formulation and Lagrangean relaxation for the cross-dock door assignment problem', *International Journal of Production Research*, Vol. 54., No. 2, pp.494–508 [online] https://doi.org/10.1080/00207543.2014.1003664.

Queiroz, M.M., Ivanov, D., Dolgui, A. and Wamba, S.F. (2020) 'Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review', *Annals of Operations Research*, pp.1–38, https://doi.org/10.1007/s10479-020-03685-7.

Ransikarbum, K. and Mason, S.J. (2016a) 'Goal programming-based post-disaster decision making for integrated relief distribution and early-stage network restoration', *International Journal of Production Economics*, Vol. 182, pp.324–341 [online] https://doi.org/10.1016/j.ijpe.2016.08.030.

Ransikarbum, K. and Mason, S.J. (2016b) 'Multiple-objective analysis of integrated relief supply and network restoration in humanitarian logistics operations', *International Journal of Production Research*, Vol. 54, No. 1, pp.49–68 [online] https://doi.org/10.1080/00207543.2014.977458.

Rekik, M., Ruiz, A., Renaud, J., Berkoune, D. and Paquet, S. (2013) 'Humanitarian and relief logistics', Vol. 54 [online] https://doi.org/10.1007/978-1-4614-7007-6.

Safaei, A.S., Farsad, S. and Paydar, M.M. (2018) 'Robust bi-level optimization of relief logistics operations', *Applied Mathematical Modelling*, Vol. 56, pp.359–380 [online] https://doi.org/10.1016/j.apm.2017.12.003.

Shammi, M., Bodrud-Doza, M., Islam, A.R.M.T. and Rahman, M.M. (2020) 'COVID-19 pandemic, socioeconomic crisis and human stress in resource-limited settings: a case from Bangladesh', *Heliyon*, Vol. 6, No. 5, p.e04063.

Shammi, M., Bodrud-Doza, M., Islam, A.R.M.T. and Rahman, M.M. (2021) 'Strategic assessment of COVID-19 pandemic in Bangladesh: comparative lockdown scenario analysis, public perception, and management for sustainability', *Environment, Development and Sustainability*, Vol. 23, No. 4, pp.6148–6191.

Sheu, J.B. (2014) 'Post-disaster relief-service centralized logistics distribution with survivor resilience maximization', *Transportation Research Part B: Methodological*, Vol. 68, pp.288–314 [online] https://doi.org/10.1016/j.trb.2014.06.016.

Sheu, J.B. and Kundu, T. (2018) 'Forecasting time-varying logistics distribution flows in the one belt-one road strategic context', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 117, pp.5–22 [online] https://doi.org/10.1016/j.tre.2017.03.003.

Singh, S., Kumar, R., Panchal, R. and Tiwari, M.K. (2021) 'Impact of COVID-19 on logistics systems and disruptions in food supply chain', *International Journal of Production Research*, Vol. 59, No. 7, pp.1993–2008.

Sokat, K.Y. and Altay, N. (2021) 'Serving vulnerable populations under the threat of epidemics and pandemics', *Journal of Humanitarian Logistics and Supply Chain Management* [online] https://doi.org/10.1108/JHLSCM-08-2020-0070.

Tofighi, S., Torabi, S.A. and Mansouri, S.A. (2016) 'Humanitarian logistics network design under mixed uncertainty', *European Journal of Operational Research*, Vol. 250, No. 1, pp.239–250 [online] https://doi.org/10.1016/j.ejor.2015.08.059.

van Barneveld, K., Quinlan, M., Kriesler, P., Junor, A., Baum, F., Chowdhury, A. and Rainnie, A. (2020) 'The COVID-19 pandemic: lessons on building more equal and sustainable societies', *The Economic and Labour Relations Review*, Vol. 31, No. 2, pp.133–157.

Wang, H., Du, L. and Ma, S. (2014) 'Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 69, pp.160–179, https://doi.org/10.1016/j.tre.2014.06.006.

Yi, W. and Kumar, A. (2007) 'Ant colony optimization for disaster relief operations', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 43, No. 6, pp.660–672 [online] https://doi.org/10.1016/j.tre.2006.05.004.

Zahiri, B., Torabi, S.A. and Tavakkoli-Moghaddam, R. (2017) 'A novel multi-stage possibilistic stochastic programming approach (with an application in relief distribution planning)', *Information Sciences*, Vols. 385–386, pp.225–249 [online] https://doi.org/10.1016/j.ins.2017.01.018.

Zhang, L. and Cui, N. (2021) 'Pre-positioning facility location and resource allocation in humanitarian relief operations considering deprivation costs', *Sustainability*, Vol. 13, No. 8, p.4141.

Zhen, L., Wang, K. and Liu, H. (2015) 'Disaster relief facility network design in metropolises', *IEEE Transactions on Systems, Man & Cybernetics: Systems*, Vol. 45, No. 5, pp.751–761.