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Key Factors Affecting Highway Freight Transportation Disruptions at Post Disaster Phase

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Abstract

A sustainable, resilient and safe freight transportation system is critically important for nation's economy. This paper discusses the basic parameters of resilience engineering and analyses freight transportation systems during post disaster phase, in order to identify the key factors affecting freight flow through transportation system during and just after a natural disaster. For this a data set of 1000 is collected by conducting a questionnaire survey to the key officials managing the freight transportation in Bangladesh. Key factors contributing to the freight transportation system is determined by Ordered probit (OP) approach. Among the factors "Damaged roadway" and "Traffic control device performance" get the highest weightage. The study findings can be utilized by the transportation officials to improve overall performance freight transportation network during the disaster and post disaster phase.

Keywords: freight transportation system; Ordered Probit; resilient transportation network.

1. Introduction

Freight transportation system and networks are critical infrastructures for the prosperity and growth of communities' at all level i.e. local, provincial, national and international. At the local level, expansion of large cities due to increasing in population has forced freight transportation system to perform effectively and efficiently to meet the increased demand. At international level, globalization has forced the design and implementation of complex large-scale freight transportation system to integrate all the means of transportation in multinomial routes for cargos. Negative impacts are generated by disruption produced by a disaster to the freight movement on the Bangladesh highway transportation network. These include emergent evacuation of people, temporary businesses closure due to delayed shipments of materials and merchandises, or postponed delivery of basic goods to the disaster-stricken regions. This paper studies the disruptive impact of natural disasters (cyclone SIDR) to the freight flow movement on the Bangladesh highway using an ordered probit modeling approach.

Bangladesh is affected almost every year by some form of natural disaster, be it floods, torrential rains, erosion, or cyclones. Of the 508 cyclones that have originated in the Bay of Bengal in the last 100 years, 17% have hit Bangladesh, amounting to a deadly cyclone almost once every year. Of these, nearly fifty-three percents have claimed more than five thousand lives. Bangladesh (2008)

Cyclone SIDR, one of the costliest disasters in the Bangladesh history, had serious negative impacts on the Bangladesh highway system. The flooding from SIDR covered 80% of the south coastal area of Bangladesh. The unique geography of Bangladesh and the coastal area's collapsed levees and floodwalls all contributed to the severe damages to its highway networks and properties. Cyclone SIDR is the most destructive cyclone to hit Bangladesh since 1991, a reported 140,000 people perished and billions of dollars damage were reported. In this instance, the death toll is significantly less (approximately 3,406), however, the damage to crop and infrastructure is significant across 30 districts, 200 Upazilas, and 1,950 unions. More than 55,000 people were injured, while over 1,000 remaining missing. Bangladesh (2008)

Since, freight flow interactions with the SIDR-affected areas are spread throughout the Bangladesh, this research is not only on highway networks in coastal areas of Bangladesh but also on the entire Bangladesh highway transportation network. It has been seen that the largest freight flow disruptions occurred to network segments at the disaster locales. However, regional and national ripple effects can also be seen significantly for the freight flow disruption over the entire Bangladesh highway transportation network. For example, most southern coastal parts of the Bangladesh took more than one year to recover, whereas the northeast regions recovered much faster. Hence, the major contribution of this research is its scale of modeling, which helps reveal that the flow disruptive factors caused by a natural disaster are not restricted to the local disaster area only. Another major effort of this research is to develop a framework to study the impact of pre- and post-SIDR freight flows through the Bangladesh highway network. Therefore, making decisions on pre-disaster preparation and post-disaster rescue freight shipping by merely focusing on a local highway network would result in sub-optimal decisions.

This paper starts with the ‘‘Introduction’’ section, which is followed by the section summarizing the relevant literature, modeling frameworks, freight databases, and the Cyclone-SIDR. The freight flow dynamics and scenarios at the national and state levels are discussed in the ‘‘Results and discussion’’ section. Highlights of findings and some remarks conclude this paper. This research was conducted from 2010 to 2015 in Bangladesh.

2. Literature Review

2.1 Previous Studies on Ordered Probit Model

An ordered probit model is a commonly used statistical technique to examine factors affecting injury severity for different crash types and locations. O'Donnell and Conner(1996) used ordered probit and ordered logit models to observe factors affecting injury severity for all crash types and all locations occurring in New South Wales, Australia. Kockelman and Kweon(2002) inspected driver injury severity by estimating separate ordered probit models for single-vehicle crashes and two-vehicle crashes. Haleem and Abdel-Aty(2010) studied crash injury severity for all crash types at unsignalized intersections in Florida using ordered probit, binary probit and nested logit models. One finding from this study of particular relevancies that young at-fault drivers were less likely to experience severe injuries. Abdel-Aty(2003) established separate ordered probit models to examine driver injury severity of crashes arising at signalized intersections, toll plazas, and road segments. Exclusive to the signalized intersection model, it was seen that at-fault drivers were less likely to sustain injuries than that of not-at-fault drivers. In the transportation research literature, bivariate ordered probit (BOP) models have been utilized to examine outcomes or decisions that may be correlated. As one example, Anastasopoulos et al. (2012a) established a BOP model to examine automobile and motorcycle ownership. Mannering and Bhat (2014) provide a summary of recent methodological approaches that have been used to evaluate both crash frequency and crash injury severity, noting several examples of bivariate/multivariate ordered probit models. Yamamoto and Shankar (2004) established a BOP model to concurrently examine the injury level of the driver and most severely injured a passenger in single-vehicle collisions with fixed objects. de Lapparent (2008) used BOP models to jointly analyze seat belt use and crash-related injury severity. Chiou et al. (2013) used a bivariate generalized ordered probit (BGOP) model to examine driver injury severity in two-vehicle crashes. There are some more studies such as Davis, G.A. (2001) used ordered probit model to relate the injury severity of a pedestrian to the speed of the vehicle for three different age groups and Siddiqui et al. (2006) examined the impact of crossing locations and lighting conditions on pedestrian injury severity. Jason D. Lemp et al. (2014) uses ordered probit model to examine the injury severity by truck movement. Also, there are many more studies (e.g. O'Donnell & Connor, 1996; Klop, 1998; Renski et al., 1998; Duncan et al., 1999) used ordered probit models to examine factors affecting injury severity.

Various ordered probit models have been calibrated to determine which attributes of the transport supply users place most importance on. The suitability of the ordered probit model lies in the specification of the utility, defined on a discrete and ordered scale as proposed in this research to score the severity of factors. Previously the ordered probit models provided successful results when applied to the study of passengers' perceived quality given that their specification defines the utility along a discrete and ordered scale. These models have been applied in the characterization of public transport quality by Tyrinopoulos and Antoniou (2008), dell'Olio, Ibeas, and Cecín (2010), Hensher, Mulley, and Yahya (2010).

2.2 Previous Studies on the impact assessment of extreme event on transportation systems:

The literature on the impact of extreme events (e.g. disasters) on transportation systems is abundant. However, the publication on the effect of freight disruption caused by an extreme event in the highway transportation network is sparse. This situation is true though in recent decades there is an upward trend of natural disaster occurrences (Haghani and Afshar (2009), such as the 1994 Northridge earthquake in the USA, 1995 Kobe earthquake in Japan, 2005 May tornado in Oklahoma City, 2005 Hurricane Katrina in New Orleans, and various man-made disasters, such as the September 11, 2001 world trade center bombing in New York City and 2002 I-40 bridge collapse in Oklahoma.

There are four types of literature available on freight disruptions due to natural disasters. One type of the current literature concentrates more on the direct physical damages and restoration to the transport network or human casualty in the disaster-affected areas rather than on the network's flow disruptions and its effects at different scales. Another cluster of the existing research emphasizes on better valuations of social and economic impacts and losses (indirect costs) caused by disaster disruptions to the transportation system. The third class of available publications is on effective delivery and re-routing to and from the disaster regions during and after a disaster. The fourth type of research is more on system-wide modeling endeavors, impact assessments, and strategies for a resistant transportation system, including the freight logistics component at local, regional, and national levels. Each of these broad groupings will be concisely reviewed.

2.2.1 Literature on Direct Physical Damage and Reconstruction

DesRoches (2006), in an edited report to American Society of Civil Engineers, provided abundant information on the transportation system's physical damage in Louisiana, Mississippi, and Alabama. The report lists the damaged 45 bridges and the damage levels on railroads and roadways, besides the detours. The bridge damage costs and engineering repair expenses from Hurricane Katrina were also reported by Padget et al. (2008). The authors observed the damage patterns to bridges and developed a relationship between storm surge elevation, damage level, and repair cost. They concluded that the damage to bridges in hurricane events take place due to storm surges, and designing on higher elevations or using simple improvements in design could help allay damage and costs.

Reconstruction of the disrupted transportation network is critical due to its vital contribution in the restoration of other lifelines. Reconstruction maneuvers on transportation networks after an extreme event can be prioritized with different perspectives such as network connectivity (Basoz and Kiremidjian 1997), network reliability and traffic flow (Wakabayashi and Kameda 1992), travel delays (Nojima and Sugito 2000), accessibility based on distance decay functions or traffic volumes (Sohn 2006), and social criteria with travel times (Chang 2003)

2.2.2 Literature on Social and economic impacts and losses

Transportation-related economic loss caused by the 1994 Northridge earthquake is estimated by Gordon et al. (1998). The research concludes that about $1.5 billion of the $6.5 billion business disruption losses could be credited to transportation, more precisely to bridge collapses and highway damages caused by the earthquake. Similar works can also be found in Cochrane (1997) and Boarnet (1998). The 1995 Kobe earthquake in Japan caused a loss of about $178 billion, comparable to 0.7 percent of global gross production (Papadakis 2006). Where's, Cho et al (2001) integrated a highway model with an Input–Output (IO) model for Los Angeles, Kim et al. (2002) developed a combined transportation network with a multi-regional IO model, and Okuyama et al (2004) developed a closed interregional IO model underlining distributional effects, which may be applicable to extreme events incurring drastic quarter-to-quarter changes like earthquakes. Haggerty et al (2008) developed a transportation-based IO framework enabling the investigation of interdependencies among economic sectors and the effects of an extreme event on freight transport.

2.2.3 Literature on Efficient delivery and re-routing

Freight transportation plays an important role by delivering needed supplies and goods to disaster regions prior to, during, or after a disaster. In the case of Hurricane Katrina, the Department of Transportation marshaled more than 1,639 trucks to support the delivery of more than 3,731 truckloads of goods, including more than 31 million liters of water, 56,400 tarps, 25 million meals ready to eat, more than 19 million pounds of ice and 215,000 blankets. Transporting these goods from distribution hubs through the disrupted transportation network in addition to the regular traffic load was obviously a challenge; hence, efficient and effective re-routing of freight trucks to the most proper alternative routes during and immediately after extreme events requires profound studies of freight movements under normal and extreme conditions.In addition, Chin et al (2006) showed a 10 % improvement in average travel time for all travelers when different routing strategies are used considering both passenger vehicles and freight trucks. In particular, after hurricanes Katrina and Rita, the scarce response to extreme events attracted consideration from the researchers and insisted the academic community to study emergency logistics and disaster response policies from the transportation planning perspective (Litman 2006). Haghani and Afshar (2009) developed a comprehensive model that describes the integrated supply chain operations in response to disasters, as well as finding the ideal location for transitory facilities considering the capacity constraints. The model can provide delays and allot limited resources ensuring the optimality for the whole system. During or immediately after the disaster, humanitarian efforts must quickly move large amounts of diverse kinds of goods and relief personnel to the disaster zone to reduce casualty and damage. Freight services by local businesses might be the agilest options as suggested by (Haghani and Afshar 2009). More research on disaster response and commercial logistics is avaiable in Beamon (2004), Beamon and Kotleba (2006), Van Wassenhove (2006), and Oloruntoba and Gray (2006). Chang (2000), in making the distinction of local hinterland cargo, from-to flow (to the rest of Japan), and through flow (foreign transportation cargo), resolved that after the Kobe earthquake, from-to and through flows suffered the maximum, resulting in both short-term revenue and long-term competitive position for the Kobe port. The study demonstrates the importance of local hinterland cargo, through freight flow, and port transshipment cargo, hence showing the port's vulnerability.

2.2.3 Literature on Resilient transportation system

Rodrigue et al. (2013) in his research shows that a disruption at a much high scale can impact the security of a whole region or nation. Increased mobility, infrastructure, and economic interdependency, the concentration of distribution, or urbanization each is regarded as having a significant impact on the threat and risk level of disasters on transportation systems. They claim that with the increasing reliance on distribution systems, a major disaster to the transportation system can have very disruptive consequences to transportation supply (i.e., modes, routes, and terminals); transportation readiness (i.e., under time-sensitive needs); and transportation vulnerability. Therefore, good transportation disaster planning should have considered risk assessment, preparedness, mitigation, response, and recovery.

There exist some other studies on the impact of the extreme event on the transportation supply and chain management. For example, Latora and Marchiori (2005) developed a network efficiency measure. Nagurney and Qiang (2008, 2009) merged flows, costs, and behaviors for supply chain network vulnerability and resilience. World Economic forum (2012) has proposed comprehensive risk evaluation to supply chain, comprising supply–demand and operational risks. Analogous studies in this direction comprise Berdica (2002), Okasaki (2003), Litman (2006), and Manuj and Mentzer (2008).

The majority of the existing research reviewed focus on a specific type of extreme event (i.e., cyclone, earthquake) and its disruption on transportation networks using different models (i.e., IO, gravity, optimization and econometric) and several assumptions. These researches mostly focus on physical damage and reconstruction of transportation components or humanitarian logistics and distribution of goods to the disaster areas. In addition, the reviewed works do not offer a general framework to study the impact of an extreme event to a transportation system at the regional or national levels, thus, limited in spatial scope and weak in system perspective.

Finally, no previous research has analysed the factors affecting the freight flow disruptions caused by the deadliest Cyclone SIDR to the entire Bangladesh highway transportation network. It would be beneficial to have a generic model that can be applied to various extreme events (cyclone, earthquake) to a transportation network so that their impacts can be cross-compared. From the above literature, it is seen that ordered probit model has been used previously to examine the severity level of various factors on different scenarios. Thus, in this research to determine the key factors contributing to the freight transportation system disruption at post-disaster phase, ordered probit model has been used successfully. A framework has been established that can be applied to any natural disaster affecting freight transportation system with slight contextual modifications. The framework, consequently, will guide transportation planners as well as emergency managers in strategic decision-making under natural disaster conditions to handle pre-disaster planning, during disaster relief endeavors, and post-disaster recovery freight movement.

3. Research Design

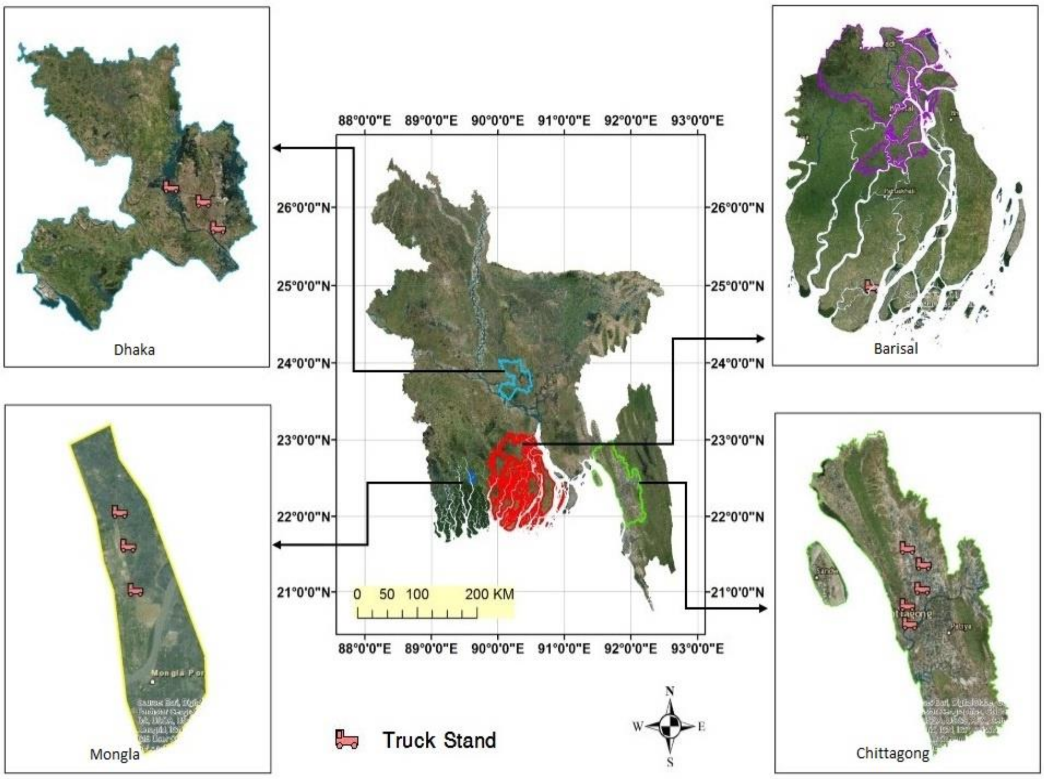
3.1 Objectives:

This research is diagnostic in nature and uses a case study method for achieving research objectives. The literature review clearly indicates that different factors would be important in different contexts. It is further seen that factors affecting the freight transportation disruption at a post-disaster phase in the context of Bangladesh, as well as other developing countries, are neglected by the researchers. Hence, an attempt is made to study the factors affecting the freight transportation disruption at a post-disaster phase in the context of Bangladesh, as well as, other developing countries, frequently affected by natural disasters.

3.2 Sampling and Survey:

As, cyclone SIDR has its effect on the entire transportation network system of Bangladesh, survey locations are selected such that these locations provide data of the entire country. Especially, truck stations near coastal areas are selected because these stations have faced the severity of cyclone SIDR the most. Figure:1 shows the locations of truck stations where the survey was conducted. Bangladesh has mainly two big sea ports: Chittagong and Mongla. A huge number of trucks move regularly by these corridors. Also, recently Paira Bandar, another seaport has become one of the main sources of freight input of this country. So survey locations are located mostly around these three sea ports. During SIDR Paira sea port and Mongla seaport has faced the severity of damage mostly. The survey form is designed after studying previous research works on freight movement. To select the factors for designing the survey form effectively, besides studying previous studies on freight transportation, a meeting was held with BRTA (Bangladesh Road Transport Authority) officials. Four groups each containing five members conducted the survey during the month December and January of 2010. Five truck stations of Chittagong, three truck stations of Mongla, one truck station from Barisal (Paira Sea Port) and three truck stations from Dhaka (Capital of Bangladesh) is surveyed. Truck drivers and truck station authorities are surveyed, with a structured questionnaire form to collect their opinions about the key factors attributing to the freight flow disruptions at post-disaster phase. Data from 1445 truck drivers and truck station authorities are collected. After filtering the anomalies a sample size of 1000 is selected as the primary data.

Figure 1: Locations of Data Collections.



3.3 Research Instrument:

Since the literature depicted that determinants vary with services, it was determined inadvisable to use any of the existing instruments. This made our task difficult but necessary for achieving the research objectives. An instrument was developed on the basis of the existing literature, observations, the pilot study, and expert opinion. Then the questionnaire was further refined. Finally, the questionnaire included twelve variables to measure the key factors affecting highway freight transportation disruptions at post-disaster phase including:

Table 1: Description of Variables.

No.	Variable Name	Variable Description
1.	Travel frequency	Number of trips made by truck per month.
2.	Excess hour traveled	The amount of extra hour the truck traveled due to disaster damage.
3.	Excess distance traveled	The amount of extra distance (in km) the truck traveled due to disaster damage.
4.	Damaged roadway	The extent to which roadway has been damaged due to disaster severity.

5.	Disaster severity	Severity level of disaster
6.	Detour performance	Performance of detour at post disaster phase
7.	Congestion after disaster	Traffic congestion due to increased traffic flow at post disaster phase
8.	Damaged network communication	Disruption in communication due to damaged telecommunication network, among truck drivers and corresponding authorities by disaster
9.	Damaged infrastructure	The severity level of damaged infrastructure (e.g. truck stations, connecting ferry, etc.) due to disaster.
10.	Resource constraints	Scarcity of resources (e.g. fuel availability, power system, availability of truck drivers, etc.)
11.	Cost Impact	Increase in cost for freight movement at the post-disaster phase and also decrease in freight demand.
12.	Traffic control devices performance	Performance of traffic control devices to ensure safe, efficient and rapid movement after disaster damage.

3.4. Preliminary Statistics:

A brief summary of preliminary statistics is shown in Table 2. For this research, data of twelve variables is taken in an ordered basis. Interpretation of data taken is given on the Table 2.

Table 2: Preliminary Statistics

Description of Variables	Mean	Standard Deviation	Qualitative Scale	Quantitative Scale
Travel frequency	2.64	1.58	Most frequent to Least frequent	1 to 5
Excess hour traveled	2.55	2.22	No effect to Severe effect	1 to 5
Excess distance traveled	3.00	1.63	No effect to Severe effect	1 to 5
Damaged roadway	3.67	2.15	No damage to Severe damage	1 to 5
Disaster severity	3.84	1.50	Least severe to Most severe	1 to 5
Detour performance	2.56	1.62	Excellent to Very bad	1 to 5
Congestion after disaster	1.97	2.09	No congestion to Chronic Congestion	1 to 5
Damaged network communication	3.76	2.26	No damage to Severe damage	1 to 5
Damaged infrastructure	3.99	1.59	No damage to Severe damage	1 to 5

Resource constrains	3.59	2.47	No effect to Severe effect	1 to 5
Traffic control device performance	3.72	2.50	Excellent to Very bad	1 to 5
Cost impact	3.5	1.56	No impact to Severe impact	1 to 5

3.5 Methodology:

The collected data were used to estimate key factors using ordered probit models. The model proposed by McKelvey and Zavoina (1975), adapts random utility theory to discrete and ordered answers, such as, those delivered by the qualitative scale of 1–5 offered in this research to express the severity level of factors to freight flow disruption.

The model is based on random utility theory where in this case the utility is represented by the quality, Q_i , comprising an observable term, βx_i , and an error component, ε_i :

$$Q_i = \beta x_i + \varepsilon_i \text{..} (1)$$

where i is the index for each observation (each user interviewed), β is the K-dimensional vector of coefficients that affect the observed attributes, x_i is the K-dimensional vector of attributes, ε_i is the error term, which is assumed to be a random variable, normally distributed in the ordered probit model, with mean zero and unit variance.

Here,
Q_i = Vector form of the severity of freight movement disruption at post-disaster phase (unobserved).
x_i = Vector form of explanatory Variables (e.g. Travel frequency, Excess hour traveled, Damaged roadway, etc.)

Since the dependent variable, Q_i , is unobserved, standard regression techniques cannot be applied to compute Eq. (1). Yet, as suggested by O'Donnell and Connor (1996), one can reasonably assume that a high severity of freight flow disruption, denoted by, Q_i , is related to a high level of observed freight flow disruption, denoted by y_i. This relationship can be translated as follows (Ye and Lord, 2014):

$$y_i = 1, \text{ if } Q_i \le \mu_{1,}$$
$$y_i = k, \text{ if } \mu_{k-1} < Q_i < \mu_{k,} \text{..............................} (2)$$
$$y_i = K, \text{if } Q_i > \mu_{k-1}$$

Where, $\mu = \{\mu_1, \mu_2, ..., \mu_k, ..., \mu_{k-1}\}$ are the threshold values for all freight flow disruption severity levels that define y_i, corresponding to integer ordering, and K is the highest ordered freight flow disruption severity level. In turn, the probability that user surveyed is *i* faces and freight flow disruption *level k* is equal to the probability that the unobserved severity of freight movement disruption at post-disaster phase, Q_i, assumes a value between two fixed thresholds. In other words, given the value of x_i, the probability that the freight flow disruption severity faced by user *i* belongs to each severity of freight movement disruption at post-disaster phase level is:

$$P(y=1) = \phi(-\beta x_i);$$
$$P(y=k) = \phi(\mu_{k-1} - \beta x_i) - \phi(\mu_{k-2} - \beta x_i); ....(3)$$
$$P(y=K) = 1 - \phi(\mu_{K-1} - \beta x_i)$$

Where, ϕ is the cumulative normal distribution function. For estimation, Eq. (4) can be written as (Washington et al., 2010):

$$P(y=k) = \phi(\mu_k - \beta x_i) - \phi(\mu_{k+1} - \beta x_i) ....(4)$$

Where, μ_k and μ_{k+1} denote the lower and upper thresholds for the freight movement disruption severity level k, respectively. For all the probabilities to be positive, the thresholds values must satisfy the restriction $\mu_1 < ....\mu_k < .... < \mu_{K-1}$. Computation of these probabilities allows the understanding of the effect of individual estimated parameters. Indeed, a positive value of β_i implies that an increase in x_i will clearly generate the increase (respectively, decrease) of the probabilities of the highest (respectively, lowest) ordered freight movement disruption severity levels. However, it is not obvious what effect a positive or negative β_i will generate on the probabilities of the intermediate levels. For this reason, the computation of marginal effects for each level is suggested (Washington et al., 2010). These marginal effects provide the direction of the probability for each level as follows:

$$P(y=k) / \partial x = [\phi(\mu_k - \beta x_i) - \phi(\mu_{K-1} - \beta x_i)]\beta ....(5)$$

The computation of Eq. (5) is appropriate only if the variable is continuous. And here, in this research variable is continuous. The thresholds μ are unknown parameters to be estimated jointly with the model parameters β. Here, both are estimated through the maximum likelihood method .

A five- point qualitative scale ranging from “most important” to “least important” was used to measure the key factors affecting the freight flow disruption. A qualitative scale was used because it allowed the researchers to quantify opinion-based items, and a scale with balanced keying (an equal number of positive and negative statements) could obviate the problem of acquiescence bias.

4. DATA ANALYSIS RESULTS

4.1 Estimations of the OP Model:

The ordered probit model was specified using the STATA software package. Factors significantly influence the severity of freight movement disruption at post-disaster were carefully identified from variables described in Table 1. The fitted ordered probit model is given in Table 2. A positive coefficient of a variable implies that the increase of the variable would increase the severity of freight movement disruption. On the contrary, a negative coefficient of a variable means that the freight movement disruption severity would be reduced by the increase of the variable.

Table 3: Ordered probit model estimation results:

Description of Variables	Co-efficient Value	Z-value	P value	Model Validation					
				Sample 1			Sample 2		
				Co-efficient value	Z-value	P value	Co-efficient value	Z-value	P value
Travel frequency	-0.204	-6.12	0.00	-0.284	-7.14	0.26	-0.246	3.77	0.00
Excess hour travelled	0.048	1.73	0.08	0.063	0.95	0.34	0.021	0.31	0.76
Excess distance travelled	0.049	1.72	0.09	0.142	1.79	0.07	0.054	1.70	0.08
Damaged roadway	0.484	13.91	0.00	0.533	7.29	0.00	0.503	6.90	0.00
Disaster severity	0.187	4.95	0.00	0.222	2.64	0.01	0.166	2.00	0.05
Detour performance	*0.026*	0.82	0.41	*0.098*	1.48	0.14	*0.039*	0.60	0.55
Congestion after disaster	*0.025*	1.12	0.26	*0.021*	1.04	0.025	*0.009*	0.31	0.75
Damaged network communication	0.092	2.87	0.00	0.094	2.97	0.49	0.239	3.51	0.00
Damaged infrastructure	0.052	1.69	0.09	0.040	1.61	0.11	0.091	2.32	0.00
Resource constrains	0.153	4.15	0.00	0.063	0.83	0.41	0.291	3.78	0.00
Traffic control device performance	-0.230	-7.11	0.00	-0.297	-4.46	0.00	-0.316	4.52	0.00
Cost impact	0.134	4.18	0.00	0.179	2.88	0.00	0.109	1.75	0.08

Coefficient Values of Variables >1.64 is considered Significant.
Italic numbers indicate 1.00<Z_value<1.64
Italic Underlined numbers indicate Z_value<1.00

Model results show that Travel Frequency has negative coefficient value (-0.204; Table 3). This value indicates that travel frequency is severely affected during post-disaster phase. A negative value of travel frequency describes the reduction in freight movement at post-disaster phase, which actually proves the hypothesis that at post-disaster phase freight movement is severely disrupted. The damaged roadway has a positive coefficient value (0.484; Table 3), indicating an increase in the severity of damaged roadway increase the freight disruption. Due to the damaged roadway and damaged infrastructure (0.052; Table 3) vehicles need more hours to travel than normal. Damaged roadway forces vehicles to alter roadways which result in an excess hour and excess distance of travel.

Of the positive coefficient value of disaster severity (0.187; Table 3), it is clear that the higher the severity of disaster the higher the amount of disruption in freight flow. On an average, two to three cyclones hit the coastal areas of Bangladesh each year. However, the severity and destructiveness of cyclone SIDR are the most for the last twenty-five years in the history of Bangladesh. Also, the disruption in freight flow due to cyclone SIDR is immense. Due to the damaged roadway and damaged infrastructure freight flow was stopped for almost four days. As a result, the people of the coastal area of Bangladesh suffered greatly in the scarcity of food and relief goods. In addition to, unavailability of fuel during post-disaster phase also exacerbated the freight flow movement.

Damaged network communication (0.092; Table 3) increases uncertainty in freight flow movement. During post-disaster phase due to damaged network communication truck drivers hardly can communicate with transport officials to get further information about the road condition. As a result of this uncertainty, truck drivers lose their willingness to travel at post-disaster phase, which directly increases the freight flow disruption.

The severity of disaster increase safety hazards in freight flow as the traffic control devices cannot operate. A negative value of coefficient (-0.230; Table 3) indicates the reduction in traffic control devices performance will increase the freight flow disruption at post-disaster phase. In addition to, reduction in the performance of traffic control devices creates uncertainty among drivers. This results in a reduction in the speed of freight flow, which increases the hour of travel also the cost of freight flow.

Resource constraints at post-disaster phase hinder the freight movement severely. It reduces freight flow time reliability and freight capacity. Unavailability of fuel forces the vehicle not to travel further and power system failure reduces the performance of traffic control devices. Also, due to failure in the power system, roadside lighting facilities stop working. All of these hinder the freight flow to the extreme.

Several variables were not found to be significantly related to freight flow disruption severity. Congestion after a disaster is found to be insignificant which actual matches the real scenario. Congestion may be caused due to rapid evacuation at pre-disaster phase. However, at post-disaster phase, there remains hardly any congestion. So congestion after a disaster has very little effect on freight flow disruption. Detour performance should have a significant effect on freight flow movement. However, in Bangladesh, the absence of detour at coastal areas causes the truck drivers to ignore the performance of detour in freight flow movement. Due to lack of knowledge truck drivers could not relate detour performance to freight flow disruption, as, they do not have any practical knowledge of it.

Table 4 shows a ranking of the variables that influence the freight movement disruption severity at post-disaster phase:

Table 4: Ranking of contributory variables:

Variable Name	Z- Value	P-Value	Rank
Damaged roadway	13.91	0.00	1st
Traffic control device performance	7.11	0.00	2nd
Travel frequency	6.12	0.00	3rd
Disaster severity	4.95	0.00	4th
Cost impact	4.18	0.00	5th

*Ranking is done based on the corresponding z-value.
*Ranking of first five variables are given only.

4.2 Marginal Analysis of the OP Model:

The coefficients of variables estimated in OP model do not directly reflect the impacts of each contributing factors on freight flow disruption severity level. The marginal effects of factors identified in OP model were computed. The estimate results were listed in Table 4. The marginal coefficients illustrate the change of occurrence probability of freight flow disruption severity by one unit increase of the input variable, keeping other factors at their mean values. A positive marginal coefficient of a variable for a particular freight flow disruption severity level means that the probability of this severity level will increase by a value equals the coefficient, as the one unit increase of this input variable, and vice versa.

Table 5: Marginal Effects of Ordered Probit Model:

Variable	Level 1	Level 2	Level 3	Level 4	Level 5
Travel frequency	0.000	-0.0318	-0.0466	0.0636	0.0151
Excess hour travelled	-0.0001	-0.0074	-0.0109	0.0149	0.0035
Excess distance travelled	-0.0001	-0.0077	-0.0113	0.0154	0.0037
Damaged roadway	-0.0008	-0.0756	-0.1108	0.1513	0.0359
Disaster severity	-0.0003	-0.0292	-0.0429	0.0585	0.0139
Detour performance	0.0000	-0.0041	-0.0059	-0.0082	0.0019
Congestion after disaster	0.0000	-0.0039	-0.0058	0.0079	0.0019
Damaged network communication	-0.0002	-0.0144	-0.0211	0.0288	0.0069
Damaged infrastructure	0.0001	0.0057	0.0083	-0.0113	-0.0026
Resource constrains	-0.0003	-0.0239	-0.0351	0.0479	0.0114
Traffic control device performance	-0.0004	-0.0359	-0.0528	0.0720	0.0171
Cost impact	-0.0002	-0.0209	-0.0307	0.0419	0.0099

From the results of Table 5, it is seen that increase in the level of severity damaged roadway will increase the flow disruption by 4.18%. Also, it is seen that increase in disaster severity will increase the freight flow disruption by 4.53%. In addition to, an abrupt increase of 4.17% in freight flow disruption is found a due reduction of traffic control device performance. However, detour performance and congestion after the disaster have very little effect on freight flow disruption. The quantitative impacts of each contributing factors on the freight flow disruption severity level can be found in the table and were not listed here. The marginal analysis of this study provides more visceral findings towards the impacts of contributing factors on each injury severity level.

4.3 Model Validation:

In this section we present a validation test for our proposed model. To investigate the validity of the model specification, we first split the data into two parts (Sample 1 and Sample 2) each having about half of the observations. We estimate two separate models with the same specification using these two samples. Table 3 presents the estimation results for these two samples. The hypothesis for this specification test is that model parameters are equal for the models estimated on these two datasets. If we fail to reject the hypothesis then the validity of our specification is established. We calculate a test statistics based on likelihood ratio (LR) as shown in Eq. (5):

$$LR = -2[LL(\beta_{full-data}) - LL(\beta_{sample-1}) - LL(\beta_{sample-2})]............(5)$$

Where's, $LL(\beta_{full-data})$ the log-likelihood at convergence of the model estimated using the full data, $LL(\beta_{sample-1})$ is the log-likelihood at convergence of the model estimated using Sample 1, and $LL(\beta_{sample-2})$ is the log-likelihood at convergence of the model estimated using Sample 2. The likelihood ratio is found to be 21.99. Also, there is almost no variation in the coefficient values for full data and sample-1 and sample-2. Thus this test validates the model specification used in this research.

5. Conclusion:

This research develops a general framework for investigating the prime factors that impede the freight flow at post disaster phase. Ordered probit approach is used for this investigation. The modeling approach followed in this paper offers a methodological flexibility that can be used to model freight transport disruption at post disaster phase taking into account different contributing factors, A sample of 1000 is used for the modeling approach, Model results show that "Damaged roadway" increases uncertainty in freight flow movement. Due to "Damaged roadway" vehicles are forced to alter their routes which increases both travel time and distance of traveling. These increases in time and distance inversely affect "Cost Impact". Due to increase of uncertainty there is a reduction in freight demand. From Table 5 it is seen that increase in the level of severity damaged roadway will increase the flow disruption by 4.18%.

Our model shows that the second factor that contributes severely to the freight flow disruption is "Traffic control device performance". Reduced performance of traffic control devices increases safety hazards in freight flow. Increase in safety hazards increases uncertainty that reduces the nominal speed of vehicles. Thus, vehicles need more time to reach their destination at post disaster phase. Also, reduced performance of traffic control devices initiates severe road accidents causing huge loss to national economy. Severity of each factor increases with the increase of "Disaster Severity". For example, from Table 5 it seen that increase in disaster severity will increase the freight flow disruption by 4.53%.

Model results also show a negative coefficient value of (-0.204) “Travel Frequency”. Actual scenario supports this result. For example, increase in disaster severity reduces travel frequency greatly which actually increases the freight flow disruption consequently. Two variables are found insignificant in this research. These two variables were used significantly in few previous studies for the assessment of post disaster transport resiliency. May be this variation in results is due to contextual differences. Underdeveloped Bangladesh roadway system hardly provides any detour facilities for the vehicles. Also, the reduction in trip number at post disaster phase makes the “Congestion after disaster” an insignificant one.

At the end, it can be said that this study provides useful insights for a better understanding of the key factors affecting the freight flow disruption at post disaster phase. The study findings can be used by the transport officials to improve the overall performance freight flow at post disaster phase. Interruption to freight transportation will certainly be caused by natural disasters. However, a resilient freight flow system will recover to normal condition very quickly. The current study findings will certainly help to build a more resilient freight transport system. Authors have plan to investigate the total economic loss due to freight transport disruption at post disaster phase by considering the variables found significant in this research.

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