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TRAFFIC SAFETY ASSESSMENT FOR A LONG TERM CONSTRUCTION PROJECT USING STATISTICAL MODELING

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ABSTRACT

Bangladesh, a developing country, being among the rapidly growing economies in the world over the past decades, has planned several transportation projects to meet its regular road congestion, to meet the future demand and to increase the mobility of the city dwellers. However, on-street construction disrupts traffic by limiting speed, reducing capacity, decreasing roadway width, sometimes creating dust, and consequently creating congestion. Reduction of effective width and dust is mainly found when construction materials and machineries are observed in the carriageway creating discomfort to the road users. The study focuses on determining the effects of the construction period of long-term projects such as Mass Rapid Transit (MRT) on traffic safety. To achieve the objectives, the computerized data gathered from Police was collected for four consecutive years 'Before' and 'During' the construction time. The impact was evaluated by comparing a Non-Work Zone section with Work Zones and the factors significantly changed during the construction period were determined by z and t statistics. Construction of MRT-6 seemed to have more than 100% adverse impact on the traffic safety nearby the stations. However, the presence of a divider, direction of movement, surface condition, surface quality, light, traffic control, road geometry, day of week etc. were found to significantly affect the increasing trend of accidents in the 'During' phase. The location of the accident hotspots was also found to be more dispersed in the catchment area of the stations due to long term construction projects during the construction. After all, this research may help to understand the change of accident rate and accident pattern due to long term construction projects as well as to identify the factors associated with the increased accidents by statistical testing in terms of developing countries.

Keywords: *MRT, Work Zone, Non-work Zone, Construction Period, Statistical Testing.*

1. INTRODUCTION

Bangladesh, a densely populated developing country in South Asia, also known as the city of traffic jams, has undertaken some steps to meet the future traffic demand and the mobility of the city dwellers. One of them includes the construction of six Mass Rapid Transits in the capital of the country, Dhaka. Among them, 20 kilometers long MRT line 6 is under construction and the progress is 72.99% up to November 2021 (DMTCL, 2021). The long construction period at the work zones may affect the behavior of passengers, dwellers, drivers, and pedestrians consequently affecting safety. However, since five more MRT line is going to be constructed shortly, it is important to know how the long construction phase affects traffic safety in the urban area of Bangladesh. This study is necessary with respect to the perspective of Bangladesh whereas several studies were observed in other countries. However, those results may not be applicable for Bangladesh being a place of heterogeneous traffic where the history of construction management is very poor. Therefore, the research questions which were endeavored to answer in this research were:

- How do accidents vary near the stations Before and During construction of MRT-6?
- How do the factors affecting the accidents differ Before and During construction?

Construction on the road may cause traffic congestion and consequently delay. Also, the road surface may become uneven, broken, rough and may have reduced effective road width during construction.

All these parameters may affect the traffic safety at the construction site if it's adjacent to any busy corridor. The specific objectives of this study were following where data of four consecutive years were analyzed for both before and during the construction of the MRT expressway:

- To compare previous and existing safety due to the construction
- To determine the factors affecting the accidents before and during the construction of MRT

This research is the first to introduce how the long-term construction projects affect the road safety in Bangladesh and how do the factors affecting during the construction vary using statistical tests in a desktop environment.

2. LITERATURE REVIEW

MRT line-6 is a fully overhead expressway going to be the route of the first electric train of Bangladesh. The roadway below the MRT line is generally a 4-lane divided or undivided highway above which the pillars have been installed, as well as the whole construction is going on. However, the effect of the construction period on nearby roadway safety isn't a very new study. Developed parts of the world such as Texas, Illinois, Washington which have undergone huge industrial development before, conducted this study concerning traffic safety interruptions during roadwork activity.

According to Graham, J.L. et al. (1977), the increase of accidents at work-zones increases by 15% and 16% respectively for crossover and no crossover in a 4 lane divided roadway where only one lane is open per direction. However, for a 4 lane undivided roadway where only one lane is open per direction, the accident rate decreased by 5% (Graham, J.L. et al., 1977). Traffic control and the type of roadway are the most important factors for the increase of accidents at the work zones (Gerald L. Ullman and Raymond A. Krammes, 1969). Work zones typically experience an increase in rear-end accidents which is the most common type of collision in the workplace (Nemeth, Z.A., and D.J. Migletz, 1978) (Richards, S.H., and M.J.S. Faulkner, 1981).

However, developing countries such as Bangladesh where the traffic management practice during the construction period is very poor may not follow the same trend as that of the developed countries. A recent study concluded that the majority of the Highway Work Zones (HWZs) of Pakistan do not satisfy the standard safety guidelines (Rashid et al., 2019). A more recent correlation analysis at the micro-level showed that with increasing volumes at the road work zone having heterogeneous traffic, the lateral movement becomes more haphazard in India (Raju et al., 2020). Now, work zones are defined as an area of highway where the construction process goes on affecting the operational characteristics of the roadway (Ravi Bhutani et al., 2016). The work zones indicated in this study are on the primary roads unlike highway work zones. The construction of the MRT line not only disrupts traffic safety but also economic losses in the form of travel time, fuel loss, speed reduction, depreciation etc. (Ravi Bhutani et al., 2016). The road capacity loss is found to be 13% due to on/ off street construction in Dhaka (Reasat-E-Noor et al., 2016)

Ullman used Z-statistics to determine the effects of the construction for the increased accidents (Gerald L. Ullman and Raymond A. Krammes, 1969). To estimate the impact of only construction on traffic safety, Gerald L. Ullman and Raymond A. Krammes (1969) isolated other factors which may affect the accident rate too and compared the expected accidents without construction with the actual number of accidents with construction. Lindsay I. Griffin et al. (1996)as well as (Gerald L. Ullman and Raymond A. Krammes, 1969) determined the comparability or the statistical significance of Non Work Zones (NWZs) with Highway Work Zones (HWZs) by comparing a G^2 value with the Chi-square distribution using the following formula.

$$G^2 = -2\sum_i \left(Comp_i * \ln\left(\frac{E[Comp_i]}{Comp_i}\right) + Cons_i * \ln\left(\frac{E[Cons_i]}{Cons_i}\right)\right)$$

However, this study would be a pioneer concerning an overall traffic safety assessment at the macro-level to find out the effect of long-term construction in Bangladesh. Accidents during the construction

period at the work zones seem to be more severe than normal (Gerald L. Ullman and Raymond A. Krammes, 1969). Type of accidents did not seem to be statistically important whereas time of day and accident severity were found important for main-lane accidents, on the contrary, service roads were not much affected during the construction period (Lindsay I. Griffin et al., 1996). The effect of construction varies upon different segments of the roadway (Gerald L. Ullman and Raymond A. Krammes, 1969). It is also found that construction had the most effect on daytime accidents in the main-lane accidents (Gerald L. Ullman and Raymond A. Krammes, 1969).
In developing countries, traffic safety can also be assessed by Traffic Conflict Techniques (TCT) which inspires human observation of accidents (Almqvist & Hydén, 1994). A microscopic traffic simulation approach was presented by (Hou & Chen, 2020) to assess traffic safety under adverse weather conditions. Using the coded information stored in the computer data bank, a detailed study of accident experience in the construction and maintenance zone was done to identify how traffic control can improve safety at the work zones at a micro-level (Ha & Nemeth, 1995).

A before-after crash study was obtained for Pavement resurfacing where road accidents didn't reduce after resurfacing rather reduced on the wet pavement (Kenneth R. Agent et al., 2004). The effect on traffic safety may not be the same for short-term and long-term construction projects. Work zones must satisfy the safety criteria however they present a cause to change human behavior by changing the road alignment and a reduced speed limit (Almallah et al., 2021). At a workplace of a 2-lane expressway in Japan, congestion and long-queue were identified as the factors affecting accident safety during construction (Xing et al., 2010). During the construction of the Riadh Metro, some soft and physical measures were taken anticipating the traffic disruptions to manage traffic and the result after the implication was successful (Alshalalfah et al., 2018). Reduced lane, shoulder width and speed were responsible for deteriorating the Level of Service during the construction phase (ERE Consulting Group, 2015).

Based on these previous works conducted in other developed and developing countries, this study nobly tried to determine the change of factors and trends during the construction period by statistical tests.

3. METHODOLOGY

The overall safety assessment of the MRT-6 stations before and during the construction was tried to determine in this study according to the methodology illustrated in figure 1.

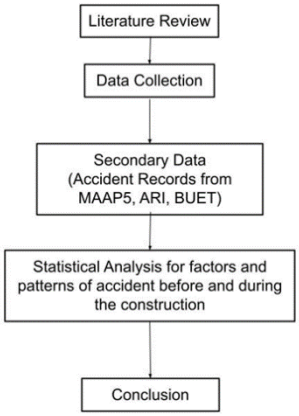

Figure 1: Research Methodology

Firstly, the accident records before and during the construction phase were collected from the Microcomputer Accident Analysis Package (MAAP5), Accident Research Institute (ARI), Bangladesh University of Engineering and Technology (BUET) for the consecutive years 2011-2015 for the 'Before' phase and from 2016-2019 for the 'During' phase of construction. The 2020 year was not considered because of Covid-19 and the travel restrictions that year. Secondly, they were analyzed to

get an overview of their variation in the pattern due to construction in a desktop environment and finally the factors affecting the safety at these places were analyzed and how the construction period affected them was obtained by statistical analysis.

4. DATA COLLECTION AND ANALYSIS

4.1 Data Collection

MRT Line-6 is of 20 kilometers having sixteen stations from Uttara to Motijheel covering Residential, Central Business District, Institutional and Mixed areas as the land use near different stations. Figure 2 below shows the location of the route having all stations and the Thanas encompassing them. The data analyzed and extracted from the MAAP5 includes the thana data since not only a small location but also a larger area may get affected during the construction phase directly or indirectly and this study aims at determining the overall assessment of traffic safety disruption during the construction period. It is to be noted that MAAP5 collects data from Road Accident Report Form by Bangladesh Police.

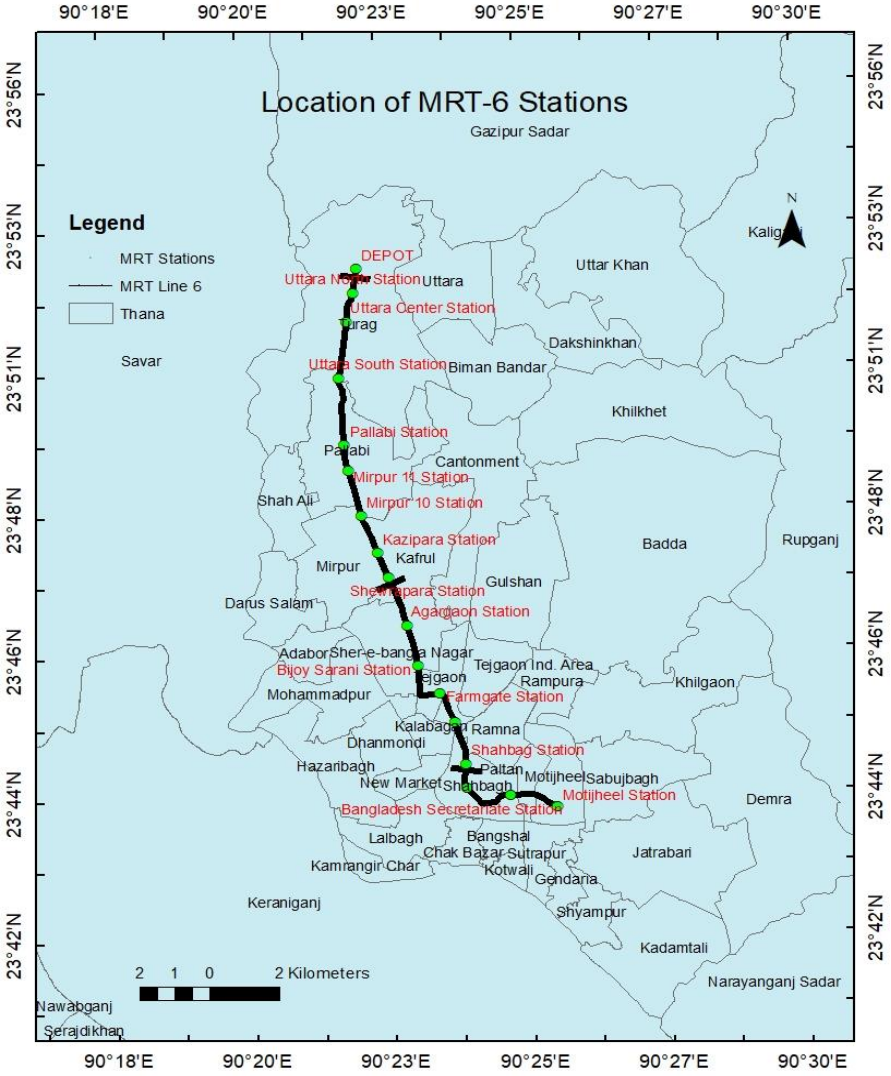

Figure 2: Location of the Study Area

MAAP5 data was collected for the Thanas under which the stations are located. Eight Thanas were found named Motijheel (4.69 sq km), Tejgaon (2.74 sq km), Mirpur (58.66 sq km), Pallabi (17 sq km), Kafrul (17.8 sq km), Turag (12.17 sq km), Shahbag (17.4 sq km) and Sher- E- Bangla Nagar (5.25 sq km) which encompass all 17 stations. The catchment area of a station depends on multiple factors; however, in literature, the catchment radius as 500 miles (area= 2.04 square kilometres) is often

introduced from the concept of half-mile walking distance (Guerra et al., 2012) although this may vary and up to 3 km (area= 28.3 sq km) is observed (Wang et al., 2016). Since the catchment area is not fixed, the effect of construction is determined for the whole thana considering the whole thana as the catchment area. The accident characteristics of the whole Thana is assumed to be the same for the catchment area of the stations under it. However, the whole locality can be affected directly or indirectly due to the construction. How accidents characteristics may vary during the construction phase is a million-dollar question when Bangladesh is going to undertake a plethora of development projects.

4.2 Comparison of the Accidents 'Before' and 'During' Construction

To determine the effect of construction only is a challenging task since nothing can nullify other associated factors. So according to the literature, a comparison section is considered to evaluate what would happen in the construction section if there were no construction. Mohammadpur thana, where presently no construction is going on, having the same heterogeneous traffic as the study area is analyzed to know how the accident rate would be if there were no construction.

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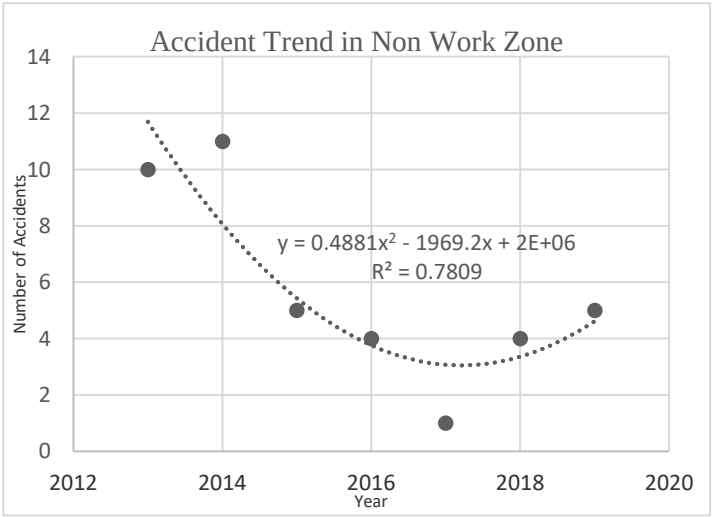

Figure 3: Accident-Frequency Trend in the NWZ Having Similar Traffic Characteristics

Figure 3 represents a good correlation among the year and the number of accidents in the Non-Work Zones (NWZs). It is also observed that for NWZs, the accident rate would decrease by 46% for the year 2016-2019 compared with the year 2013-2015. As the traffic characteristic is the same (heterogeneous, 4 lanes divided and undivided with side friction) among the thanas of studied Work Zones (WZ) and NWZ (Mohammadpur), it is assumed that this decreasing rate and trend would also prevail in the WZs too if there were no construction.

Therefore, according to Gerald L. Ullman and Raymond A. Krammes (1969),

$$\frac{Accidents\ Observed - Accidents\ Expected}{Accidents\ Expected} * 100\%$$

$$= \frac{(1 + .27) - (1 - .46)}{(1 - .46)} = 135\%$$

The expected accident was 46% less, but the actual is found an increase of 27% during the construction phase. Therefore, the effect of construction on road safety is almost 135% higher nearby the MRT-6 stations which is for mainly 4 -lane divided and undivided roads having mixed traffic. This assembles that the rate of accident is 2.35 times higher during the construction phase.

However, it is needed to validate the comparability of the comparison section (Mohammadpur thana) with the construction sections. The G^2 value from section 2 using Gerald L. Ullman and Raymond A. Krammes (1969) would be compared with the chi-square value for the significance of comparison.

$$=-2\left(14*16*\ln\frac{46}{14}+313\ln\frac{133}{313}\right)$$
$$=6$$

For the 4-year construction period, for the log-likelihood ratio with the degree of freedom= 3 (Number of years analyzed-1), the critical Chi-square value= 7.8142 whereas, the G^2 value is obtained to be less than the critical chi-square value. The expected values of accidents in the comparison and construction sections are determined from the accident trend of the previous years. The G^2 value being less than the critical chi-square value proves the fact the construction sections and the comparison section are significantly comparable.

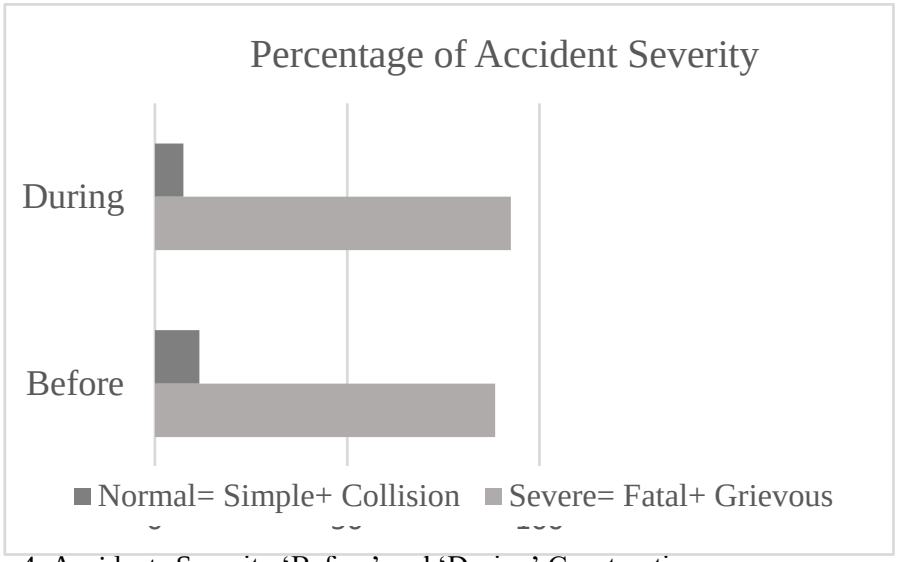

Figure 4: Accidents Severity 'Before' and 'During' Construction

Figure 4 illustrates that the accidents are more fatal and grievous during construction than they were before the construction period. This is also supported by findings of the previous study (Gerald L. Ullman and Raymond A. Krammes, 1969). There is an increasing trend found at the MRT-6 stations during the construction phase. The fatality of accidents increased by 30% and the number of Grievous Accidents increased by 60% during the construction than before the construction phase which means the percentage of the increase of severe accidents is greater than the percentage of population increase (35%) cause the demographic condition shows a trend of about a 35% increase in the population of the urban area in the 'During' construction phase with respect to the 'Before' construction phase (Bangladesh Bureau of Statistics, 2015). Therefore, it's alarming that the population growth is less than the increase of grievous accidents during construction.

Table 1: Variation of Affected Vehicles, Drivers, Passengers and Pedestrians 'Before' and 'During' Construction

	Increased by (During)
% Vehicles Engaged	7.6%
% Driver Casualties	13.3%
% Passenger Casualties	-14.4%
% Pedestrian Casualties	6.6%

Table-1 shows that the number of Affected Drivers, Vehicles and Pedestrians all have increased except the number of passenger casualties. The possible reason can be explained from the following figure 5.

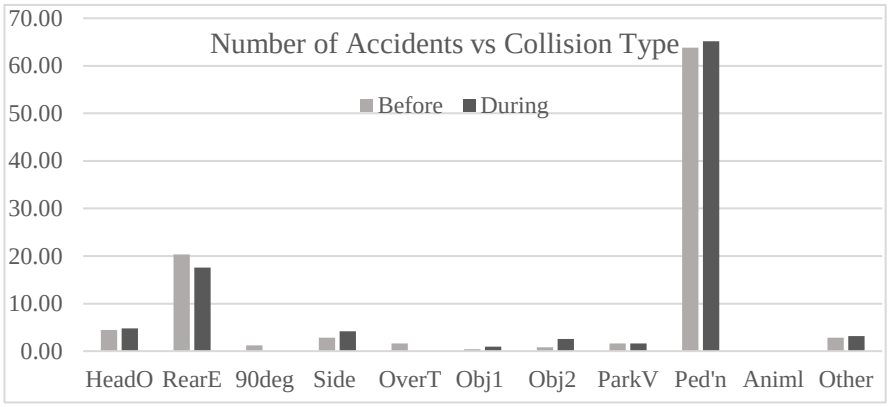

Figure 5: Collision Type 'Before' and 'During' the Construction

Figure 5 shows that accidents have been increased for every type of collision except the Rear-end collision and the most vulnerable to accidents are still the pedestrians. The locations of the accidents were also found to vary 'Before' and 'During' the construction period. Locations in the form of a code were filtered out from MAAP5 and after comparing them with a hardcopy map, their latitude and longitude were obtained and finally showed in ArcGIS to determine their hotspot's variance during the construction of the MRT-6. An 800-metre buffer is considered as a catchment zone from where people are assumed to actively use the MRT. Before the construction, the black dots were found to be concentrated mostly near the Mirpur-10 Roundabout which is practically an intersection, and it is so common for an intersection to be an accident hotspot. However, during the construction, the red dots are more dispersed in the catchment area of the stations meaning the scattering of accident locations unlike being concentrated in a particular location. Only one thana (Mirpur) is shown in the ArcGIS map for simplicity however same result is obtained for other 7 thanas.

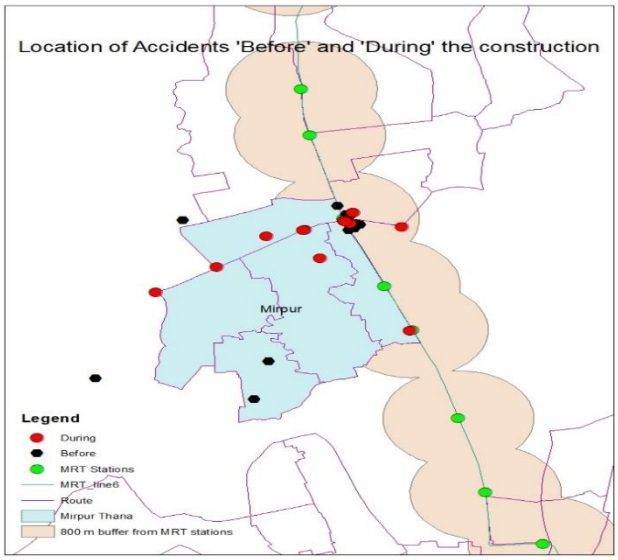

Figure 6: Spatial Distribution of Accidents at Mirpur Thana 'Before' and 'During' the Construction

4.3 Contributing Factors to the Accidents at the Stations

Secondary data from MAAP5 was collected and analyzed for identifying the factors associated during construction time with the traffic safety. A total of fifteen factors were evaluated which are Time of the Day (ToD), Month of the Year (MoY), Day of the Week (DoW), Weather, Road Surface, Road Geometry, Road Class, Road Feature, Surface Quality, Surface Condition, Surface Type, Junction type, Movement, Divider, traffic control etc.

To determine the statistical significance of the abovementioned factors during the construction period, at first, the t-statistic value was compared with the critical probability for both equal mean and variance at a 95% confidence level. If the probability value is more than 5%, the null hypothesis is accepted meaning the parameter didn't change significantly during the construction period to affect the increasing accidents. The lower the p-value, the greater the statistical significance of the observed value and a t-test is mostly used to evaluate such significance when the sample size is less than 30 which is justified in this study. It is obtained from the t-test that DoW, Light, Traffic Control, Month, Divider, Road Class, Surface Condition have changed significantly whereas other factors might not have changed severely to affect the accident although their proportion has been changed in the next years in the construction zones.

However, a z- test can also be performed like the literature (Gerald L. Ullman and Raymond A. Krammes, 1969) to compare with the t-test results and to check how the construction period affected the parameters.

$$Z = \frac{\ln\left(\frac{Cons_{During}}{E\,[Cons_{During}]}\right)}{\sqrt{Var\left(\frac{Cons_{During}}{E\,[Cons_{During}]}\right)}} = \frac{\ln\left(\frac{Cons_{During} * Comp_{Before}}{Cons_{Before} * Comp_{During}}\right)}{\sqrt{\frac{1}{Comp_{Before}} + \frac{1}{Comp_{During}} + \frac{1}{Cons_{Before}} + \frac{1}{Cons_{During}}}}$$

At a 95% confidence interval when critical Z-value= 1.96, calculating with the distribution's mean and variance, the Z-value being greater than Z-critical shows that the Presence of Divider, Surface Quality, Surface Condition, Movement, Light, Traffic Control, Road Geometry and DoW have significantly been affected during the construction period consequently increasing accidents near the work zones.

The results of the z-test and t-test match unlike the case of following 3 parameters: Month, Surface Quality and Road Geometry. However, the both test results are taken for discussion below since the t-test is supposed to provide a better result for small sample size and the z-test is justified from the rationale.

Table-2 and table-3 following represent the significance of the factors using t and z-test respectively.

Table 2: Statistical Significance of Parameters Using t-Statistics

Parameters	P(T<=t) two-tail equal mean	Z-test (two-sample for means)	P(T<=t) two-tail equal variance
DoW	0.0664	3.192	0.0273
Light	0.0443	2.341	0.0412
Traffic Control	0.0116	1.986	0.7571
Collision Type	0.1788	1.649	0.7939
ToD	0.1258	1.214	0.1232
Movement	0.4718	1.980	0.0732
Divider	0.0632	2.195	0.0078
Junction Type	0.1041	1.582	0.6917
Month	0.0150	1.831	0.0129
Road Geometry	0.2135	3.122	0.7898
Weather	0.3603	1.945	0.8648
Road Class	0.0408	1.977	0.7940
Road Feature	0.4117	1.613	0.8635
Surface Condition	0.0323	2.653	0.8647
Surface Type	0.4573	1.321	0.8699
Surface Quality	0.3475	2.316	0.8650

Table 3: Statistical Significance of Parameters Using z-Statistics

The road geometry is not found to be responsible for increasing accidents according to t-test unlike the z-test. Road geometry means reduction of road width, uneven broken road which prevalently occurs in the work zone as well as observed in the literature too (Reasat-E-Noor et al., 2016).

Table 4: Road Geometry Change During Construction

Road Geometry	Before	During	Percentages Increased
Straight	230	276	20
Curve	12	26	117
Slope	3	5	67
Curved Plus Sloped	1	3	200
Crest	0	0	0

Other two unmatched parameters' distribution (Month and Surface Quality) are showed in the following tables:

Table 5: Monthly Variation of Accidents

Month	Before	During	Percentages Increased
Jan	29	29	0
Feb	21	22	5
Mar	15	26	73
Apr	14	28	100
May	17	22	29
Jun	20	32	60
Jul	19	33	74
Aug	31	25	-19
Sep	28	28	0
Oct	18	20	11
Nov	14	26	86
Dec	20	22	10

Table 6: Surface Quality of Accidents

Surface Quality	Before	During	Percentages Increased
Good	237	296	24.9
Rough	7	12	71.4
Repair	2	5	150

Tables 4, 5 and 6 are self-explanatory representing that during the construction period months named March, April, June, July and November have a higher percentage of accidents. Percentages of accidents increase is greater in the rough and repairing road surface. Also, the curved and sloped parts of the roadway were found to be more vulnerable towards the increase of road accidents.
DoW, Light, Traffic Control, Movement, Divider, Road Class, Surface Condition are found to be significantly responsible for the increase of accidents during the construction.

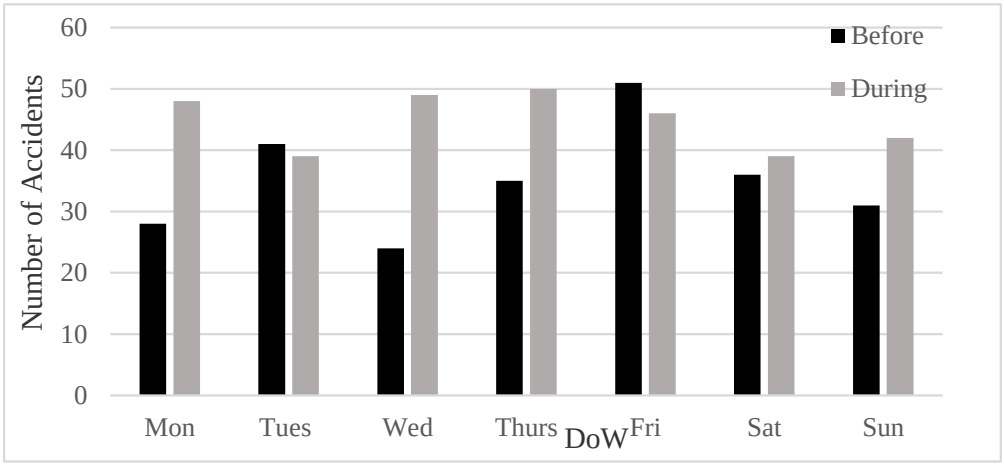

Figure 7: Daily Variation of Accidents

Figure 7 represents how the number of accidents increased During the construction phase. Friday, which is the weekend in the study area, had a dominant number of accidents before whereas weekdays are also prevalent now.

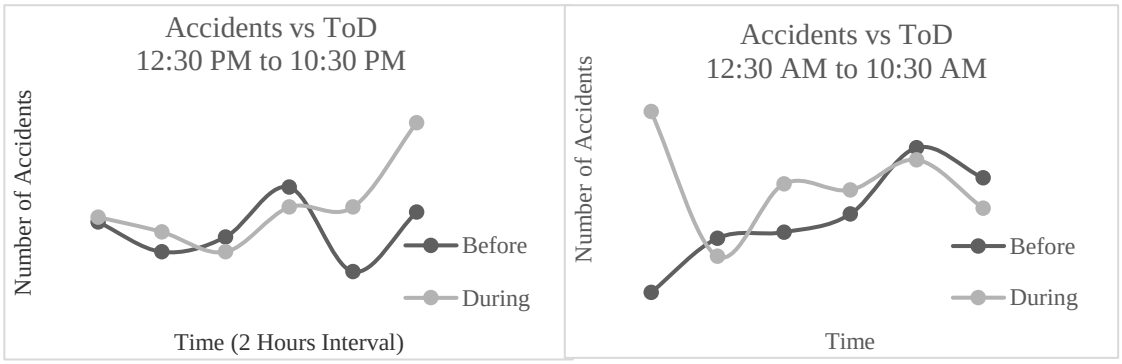

Figure 8: Hourly Variation of Accidents

For example, the prevalent time of the accident was 6:30 PM & 8:30 PM meaning at evening peak and night-lit. However, during the construction period, the dominant time was found as 10:30 PM and 12:30 AM indicating midnight. This shift from 1st third to 2nd third part of the night suggests special traffic management during this 10:30 to 12:30 PM.

Table 7 represents the vulnerable locations of the accidents before and during the construction phase. It is seen that the accidents at the Roundabouts and the cross Junction have increased greatly, which warrants special traffic management in these types of the junction.

Table 7: Accidents Concerning Junction Type

Junction Type	Before	During	Percentages Change
Not Junction	118	128	8
Cross	52	68	31
Tee	32	30	-6
Staggered	3	2	-33
Roundabout	8	19	138
Railway	2	0	-100
Others	31	65	110

Table 8: Accidents Considering Presence of Divider

Divider	Before	During	Percentages Increased
Yes	186	241	30
No	60	72	20

Table 9: Accidents Considering Direction of Movement

Movement	Percentages Increased
1-way	48
2-way	1

The following table 8 and figure 9 explain some factors the z-statistics result in an understandable form. Accidents for the roads having 1-way movement have been increased by 48% and also accidents for the Head-on Collision increased unlike of Rear-end Collison during the construction. The reason behind maybe roads which were constructed for 1-way is used as 2-way during the construction consequently increasing the percentages of both Head-on Collison and 1-way movement simultaneously. Also, the roads having dividers were seemed to be more responsible for an accident meaning insufficient divider. However, the percentage of accidents increased in the roads which have no divider is 20%, that is not much less.

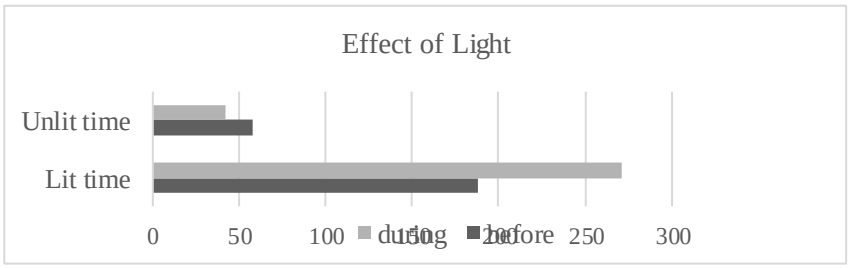

Figure 9: Effect of Light on Accidents

From figure 9, the curved and sloped part of a road during the lit time (both daytime and nighttime) needs special attention near the workplace. Accidents at Lit time (both day and night) increased whereas at dawn/ evening or unlit time decreases during construction which is very practical because the traffic volume is larger at this time meaning the lit time accidents are more affected by construction.

5. FINDINGS AND DISCUSSION

Important findings from this study are more specific in the context of developing countries where heterogeneous traffic prevails. They are listed below:

- Long-term construction project like MRT imposes an adverse effect on traffic safety for about 135% compared to the 'Before' construction phase and the comparison section. Accidents have increased by 46% during the period which would decrease by 27% for the absence of construction in a 4-lane divided or undivided urban setting. However, the proportion is about 15% and 16% for a developed country of the same road class. Therefore, some physical and soft measures are needed to be taken for example: converting major roads into temporary one-way roads, parking management, junction improvements, shifting working hours, construction of bypass road, modification of traffic signal, dedicating lane etc.
- The rate of accident is 2.35 times higher during the construction of MRT-6, which is really alarming, and the increasing rate of accident rate is even more than the population growth rate.
- Lit time (both day and night) accidents are more affected by construction whereas, in literature, it was observed that daytime accidents are more vulnerable.
- The direction of movement, presence of divider, surface quality, surface condition, road geometry, light, Day of Week etc. significantly affects accidents during construction. In literature, the congestion, reduction of road width, light etc. shed light during the construction phase in a developed country setting. For example, the roundabout, lit time, curved and sloped,

1-way movement, having divider, head-on-collision etc. are observed to be more sensitive here. Therefore, traffic management plan is needed to provide special attention particularly in those.

- From the ArcGIS, the location of accidents got more dispersed in the catchment area of the stations where the stations may affect during the construction period. This indicates a fixed junction or intersection is not the accident hotspot anymore, rather the catchment area in a whole is affected.
- T- tests were used to identify the factors which significantly have been changed during the construction period. A t-test is supposed to provide a better result in a small sample size and z-test is used in the literature, so both test results are combined to identify the factors associated with the increase of accidents during the construction. It is to be noted that the factors identified from the two tests are almost similar.

Construction projects when undertaken should employ special treatment for the associated factors which significantly affects so that the accidents rate affected by 135%.

7. CONCLUSIONS

The research has a practical significance to understand the risk associated with long-term construction projects in a country like Bangladesh where a huge infrastructural development is going to be implemented soon. However, there were some limitations during the study for example the X-Y co-ordinate of all accidents were not found. Also, this factor and impact analysis are completed on a desktop environment. However, some primary data, for example, video data near the stations might help to analyze in International Road Assessment Program iRAP and to compare the result with statistical results to get a real-life comparison.

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