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Evaluation of Economic, Environmental and Safety Impact of At-Grade Railway Crossings on Urban City of Developing Country

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Abstract- Running through the densely populated urban areas railway has an inherent weakness of generating congestions at the at-grade crossings or level crossings (LC). It is responsible for economic losses, emission of harmful gases, and increase in accident risks for roadway traffic. Realizing these effects many of the developed countries have adopted various solutions starting from automatic gates installation to grade separation. However, developing countries have either failed to address the congestion problems caused by LCs, or yet to adopt appropriate measures to counteract them. Dhaka, the most densely populated megacity of the world has 42 level crossings in the city. This study reveals the economic losses, environmental impact and safety hazard of the busiest 7.15 kilometer railway corridor which has six level crossings. Primary field data have been utilized to find the delays and emission incurred by individual LC using available methods with slight modifications. Yearly economic losses incurred by studied LCs are estimated to be 32.95 million USD. With 1,412,128 kilograms of harmful gases (volatile organic compound, NOx and CO) emitted in a year, these LCs pose serious threats to the public health of the surrounding neighborhoods. Hazardous locations have been identified by assigning Hazard Index values. In light of these results, suitable solutions have been proposed to reduce congestion at the level crossings, and to enhance public health and roadway safety.

Keywords: level crossing, developing country, economic loss, emission, hazard index.

I. Introduction

Railway has been the most efficient way to meet the transportation demand of the mega cities throughout the world. Running through the densely populated urban areas, railway has an inherent weakness of producing congestions at the at-grade crossings (level crossing or LC). Especially near intersections, at-grade crossings create numerous conflict points for road-traffic, trains, and pedestrians. These crossings force both road traffic and trains to reduce their speed, increasing travel time, and congestion and decreasing overall efficiency of the rail network. The at-grade crossings are also a major source of traffic accidents in the urban areas, thus producing a significant threat to economy as well as to public safety.

Grade separations have been adopted in different countries to eliminate the at-grade crossings. Different criteria are used as base for the consideration of grade separation of level crossings in different countries. Australia, Germany, Great Britain, USA, Spain, Canada and various other countries used train speed as a criterion. In Japan the official regulation is followed as a grade separation criterion which states that if the product of daily vehicle traffic and the number of hours when the crossing is closed because of trains exceeds 10,000, the crossing is to be grade separated (Katz and Guttmann, 1991). Like the developed country, developing economies may not be able to adopt this solution as grade separation is very costly. Installing automatic level crossing gates, synchronizing the arrival time of trains with roadway traffic signals, appropriate platform arrangement near to the crossings are some of the less costly alternatives.

Dhaka is one of the most densely populated megacities of the world. It has a population of over 15 million with a staggering density of nearly 43,000 people per square kilometer area. Bangladesh Railway (BR) is the state-owned rail transport agency of Bangladesh. Both inter-city and suburban rail systems are operated under the state owned BR on a multi-gauge network of broad, meter and dual gauges. Presently, BR has about 2541 (1413 Approved & 1128 Un-approved) level crossing gates all over the country (Bangladesh Railway, 2008). In Dhaka, there are 29 authorized level crossings which are devised with manually operated gates. Daily on an average 90 trains travels to and from the Kamalapur Railway Station situated near the central business district (CBD). Most of the trains travel to the northern part and out of the city; only few passenger trains and DEMU trains travel south from the Kamalapur Railway Station. This creates severe congestions at the level crossings and is responsible for road-rail accidents. Some of the level crossings located in the busiest roadways are responsible for huge economic and travel time losses, and poses threat to roadway safety.

With the population growth traffic are growing faster than ever. This is high time to address the economic losses and safety issues related level

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crossings of Dhaka city. This study aims at finding out the economic losses, environmental pollution and threats to public safety associated with some of the most congested and accident prone level crossings of Dhaka. With some modifications, available methods are used to estimate the economic losses, environmental pollution and safety threats using primary field data. Also, some probable solutions are reviewed and the suitable ones are recommended.

This research paper is divided into several sections. The next section describes the available methods to estimate delays and their economic implications, which is followed by the selection of study locations and study methodology. The analyses of the study have been divided into three sections afterwards. In light of the findings some suitable solutions have been recommended in the section before the conclusion.

II. Literature Review

The literature review section focuses on the available methods to calculate vehicle delay and to estimate economic losses incurred by the at-grade crossing. The available methods of risk assessment on the at-grade crossings are also discussed here.

a) Delay Estimation of Isolated Crossing

Most of the grade crossings were somewhat isolated from traffic signalized intersections, thus making them well-suited for use of a mathematical model such as the Webster uniform delay model (Okitsu et al. 2010), which is based on classical deterministic queuing theory. Total vehicle delay caused by each blockage event is calculated using the formula below:

$$D = [AR * Q * (B + LT)]/2 \tag{1}$$

Where:

D = Total delay in vehicle-hours;
B = Duration of blockage event in hours
AR = Vehicle arrival rate in vehicles per hour;
LT = Lost time in hours
Q = Queue Duration in hours.

Queue duration is the period starting when the gates begin their descent and ending when the vehicles queued at a crossing dissipate after a gate blockage event. Queue duration is estimated based on the following formula:

$$Q = (\text{Blockage Event Duration} + \text{Lost Time}) / [1 - (\text{Arrival Rate} / \text{Saturation Flow Rate})] \tag{2}$$

A traffic delay calculation model was proposed by Hakkert and Gitelman (1997) from slight adjustment of a previous model by Rayan and Erdman (1985). That model includes:

$$T = \sum_{\substack{i=l,m \\ j=l,k}} \frac{1}{2} t_{cl_i} [t_{cl_i} + t_{rel_{i(j)}}].\lambda_j.n_{i,j} \tag{3}$$

Where, m = number of train categories for the period;
k = number of time intervals with different traffic volumes;
t_{cl_i} = blockage time caused by i-type trains;
$t_{rel_{i(j)}}$ = queue release time after i-type trains for the interval with j traffic volume;
λ_j = vehicle arrival rate at the crossing during the interval with j traffic volume; and
$n_{i,j}$ = number of i-type trains during the interval with j traffic volume.

Equation 2 provides simpler means to measure the delays than equation 3. In this study equation 2 has been used to estimate the delays of individual level crossing.

b) Estimation of Economic Cost at Grade Crossing

Economic cost incurred in grade crossings depends on several factors. Number of trains passing during the measured time (peak hour, a whole day etc.), total vehicular traffic using that crossing, blockage duration for each train event, reduction speed of vehicular traffic etc. The relationships between these factors and economic losses are linear in most cases. Hakkert and Gitelman (1997) proposed a linear regression formula for the approximate evaluation of the economic loss per crossing due to road traffic delay. The general formula is:

$$y = \alpha + \sum_{i=1}^{n} \beta_i x_i \tag{4}$$

Where, y = annual cost of vehicle delays in million NIS.
β = coefficient derived from regression analysis.
x = variables used in the estimation (daily vehicular traffic, number of crossing per day, free speed of vehicle on road etc.)

For a number of variables different values of coefficient were derived. Using equation 3, estimation of economic losses can be made by using at most five variables (Hakkert and Gitelman 1997). Without any speed data, the following equation was proposed (Hakkert and Gitelman 1997):

$$y = 0.00014x_1 + 0.010387x_2 + 0.361153x_3 \tag{5}$$

Where, x_1 = volume of daily vehicle traffic (vehicle per day, vpd)
x_2 = the number of crossing closing per day
x_3 = the number of hours per day when the crossing is closed.

Gitelman et al. (2006) used the following equation to estimate the annual cost of vehicular delays at a crossing:

$$D = 260[N*d_1 + (V-N)*d_2] \tag{6}$$

Where, D = annual cost of vehicular delays for 260 working days in a year.

V = daily Vehicular traffic volume

N = number of vehicles stopped at the crossing per day

d_1 = average cost of a vehicle's stopping at the crossing

d_2 = average cost of a vehicle's slowing down at the crossing

The delay costs on weekends were considered minor and hence were neglected. The economic loss sustained from traffic delays (d_1 and d_2) consisted of additional fuel consumption and other vehicle expenses (Vehicle Operating Cost), and from the time lost to vehicle occupants because of "velocity cycles" when passing the crossing (Value of Travel Time).

The same author also proposed two variant of an approximate formula for estimating economic losses incurred by grade crossing:

Y = − 0.656044 + 0.000108V + 0.0023038 trains + 0.094042 slowdown. And

Y = − 1.529568 + 0.000314V + 0.001676 trains. (for rural crossings)

Y = − 0.818024 + 0.000109V + 0.010480 trains. (for urban crossings)

Here, Y is the annual economic loss due to vehicle delays at a crossing in million NIS (New Israeli Sheqel; 1 USD = 3.78 NIS = 77.74 Bangladeshi Taka or BDT and); V refers to variable used (daily traffic volume vehicles), trains means the total number of trains, and slowdown is the average vehicle speed reduction due to a crossing in km/h.

In this research a direct approach has been adopted to estimate the economic losses in terms of vehicle operating cost (VOC) and value of travel time (VOT).

c) *Hazard Index Measurement*

A recent study identified five success factors largely responsible for the reduction in crashes, namely: commercial driver safety, locomotive conspicuity, more reliable motor vehicles, sight lines clearance, and the Grade Crossing Maintenance Rule (2).

Based on four crossing characteristics a Hazard Index (HI) equation was proposed by (Gitelman and Hakkert 1997). These characteristics included warning device, volume of vehicle traffic, and volume of train traffic and visibility conditions. Hauer (1986) proposed using an estimator T, where T is defined by:

$$T = f(x), E(x), VAR(x)); \qquad (7)$$

This method supports the maximum likelihood estimate of expected accident numbers for entities with observed accident count x, the sample mean E(x) and the sample variance VAR(x). In this manner, the influence of these characteristics on crossing safety is measured. The existing models (Taggart et al.,1987; Tustin et al.,1986) use from three to thirty factors to predict the accident potential at a crossing.

In this study New Hampshire Hazard Index (Ogden, 2007) was calculated for each of the six crossings. Calculated Hazard Index (HI) ranks crossings in relative terms; i.e. the higher the calculated index, the more hazardous the crossing. This mathematical HI helps to enhance the objectivity.

The New Hampshire Index is as follows:

$$HI = (V)(T)(P_f) \qquad (8)$$

Where, HI = hazard index

V = annual average daily traffic (AADT)

T = average daily train traffic (ADTT)

P_f = protection factor

= 0.1 for automatic gates

= 0.6 for flashing lights

= 0.8 for flashing lights with manually operated gates.

= 1.0 for signs only.

III. Selection of Study Locations

There are 42 railway level crossings and 6 railway stations in Dhaka city between Jurine and Abdullahpur of which 29 level crossings are authorized and other 13 are of unauthorized (Bangladesh Railway, 2008). 20 of these level crossings are associated with major roads and remaining 22 are associated with minor roads. For investigation, selection of crossings did not rely on an existing inventory, as it does not provide updated information about the level crossings. The major concern is to determine the economic losses, and have an estimate of the safety hazard of level crossing; following criteria are considered in selecting the study locations:

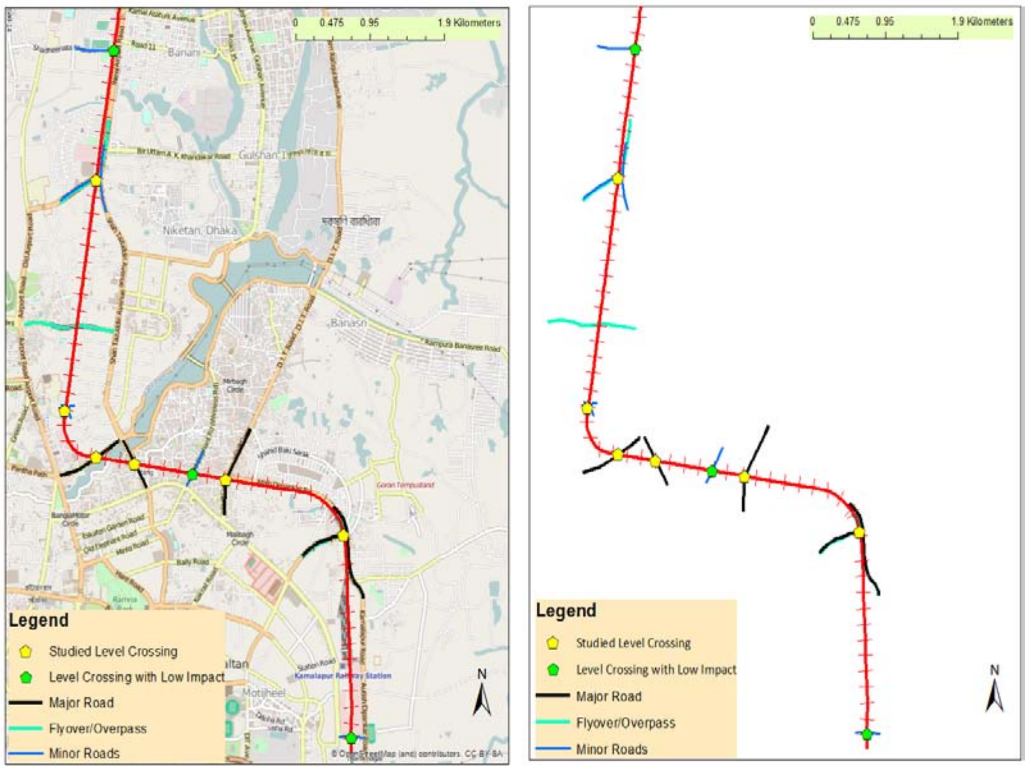

Fig. 1: Locations of the Studied Level Crossings

a. High Traffic Volume; especially those with high percentage of motorized vehicles.
b. High frequency of train traffic.
c. High duration of blockage event.
d. High rate of accidents reported in recent times.
e. High residential or commercial activities in the surrounding areas.

Based on these criteria six level crossings have been identified as critical. These level crossings sites along with the section of the railway track considered in this study have been marked in the following figure.

The selected six level crossings fall in a line starting from Mohakhali and finishing at the Kamalapur Railway Station. Length of this corridor is 7.15 km; that makes 1 LC at every 1.2 km within this densely populated area. Specially, starting from Truck Stsand to Mogbazar, there is three LC within 1.22 km of railway track. Mohakhali and Khilgaon LC have flyover (Fig. 2) running over them. But still the congestion is high in these two locations. Another flyover: Mouchak-Mogbazar flyover, is under construction which will pass over Mogbazar and Malibag LC and also will have an on and off ramps close to Karwan Bazar LC. Analyzing the aftermath of flyovers at Mohakhali and Khilgaon will help to assess the near-future scenarios at Mogbazar, Malibag and Karwan Bazar LC when Mouichak-Mogbazar flyover will be in operation.

IV. Study Methodology

The vehicle delay for the peak hours; (morning peak of 3 hours and evening peak of 3 hours, total 6 hours) is calculated for each blockage event and for each direction recorded during a single working day. Equation 1 is used to calculate the delay. The total daily (24 hours) vehicle delay is then estimated. The vehicle delay for the off-peak hours (18 hours) is taken to be half of the total peak 6 hour delay.

This mathematical model relies on only a few parameters, such as motor vehicle traffic, duration of the blockage, and the saturation flow for departing vehicles once the blockage is removed. This makes it easy to calculate delay for a given direction of traffic. The formula fits in a cell of a computer spreadsheet.

Primary field data were collected for the frequency and duration of the crossing gate blockage events in May 2015. It was observed that vehicles continued to traverse through the crossing when the warning lights flashed; in some events vehicles were found to traverse until the gate arm had fully closed the crossing. As soon as the gate arm began to rise, the vehicles in the queue began to traverse through the crossing. Therefore, for the delay analysis, the gate blockage event duration is considered to be the time when the gate arm was completely down until the gate arm begins to rise. Most of the time, a single train was observed to traverse through the crossings during the blockage events. In some cases, two trains traversed through the crossing on different tracks in different/same directions during a single blockage event.

Vehicular arrival rate is the number of vehicles arriving at the grade crossing within an identified time period. The arrival rate is based on the traffic count data collected with from field in May 2015 at each crossing over a 6-hour period (morning peak 3 hours and evening peak 3 hour). As the traffic stream consisted of different types of vehicles, to have the vehicular rate Passenger-car-equivalent (PCE) factor was used. However, for delay estimation in vehicle-hour at the rail crossings during a gate blockage event, the number of vehicle arrivals during the hour when the gate was down was recorded as the vehicular arrival rate. Delay in vehicle-hour was calculated for a single event and multiplied by the total number of gate blockage events observed during the peak 6 hours.

The maximum flow rate of the vehicles of a lane group observed during the traverse immediately after the gate blockage event is the saturation flow rate. Any start-up lost time prior to queue dissipation after the end of a gate blockage event is excluded in saturation flow rate. For the six different grade crossings different values of saturation flow were observed. Saturation flow rate was calculated in PCU per hour.

The time difference between the gates starts to rise and saturation flow stabilizes is the lost time. From the observation it was found that it took as long as 30 seconds to restore the normal traffic flow after the gate arm starts to rise. The lost time was added to the total blockage event duration.

The queue length was determined at the end of blockage event duration plus the lost period. Maximum total queue is the maximum number of vehicles waiting at the crossing during a single event. From the field the maximum queue length for each event was observed and recorded.

V. Economic Losses and Emission Cost of Delay

Delay for each crossing is measured by using equation 1. Vehicle Operating Cost (VOC) and Value of Travel Time (VOT) are well established measure of economic loss incurred by traffic congestion. In this study direct approach is used to calculate VOC and VOT from the calculated delay. The established VOC and VOT for different types of vehicles are extracted from RHD (Roads and Highways Department) Road User Cost (2004-2005). Table 1 shows the volume in PCU (Passenger car unit) with their delays and estimated losses in terms of VOC and VOT.

Table 1: Characteristics and Economic Losses of Investigated at Grade Crossings. (for 90 daily train events)

Sl	Location	AADT (PCU/hr)	Average BED per Closing (second)	Delay (veh-hr) in a Year[a]	Total Delay (veh-hr) in a Year [b]	Annual VOC in USD	Annual VOT in USD	Total Yearly Economic Loss[a] in USD	Total Yearly Economic Loss[b] in USD
1	Mohakhali	79099	172	1038977	1558465	1,922,275	4,283,667	6,205,943	9,308,914
2	Truck Stand	57279	200	302786	454179	144,808	253,454	398,263	597,394
3	Karwan Bazar	86414	222	1156900	1735350	1,145,876	2,117,879	2,291,753	3,437,629
4	Mogbazar	104465	219	1882394	2823591	2,869,598	6,106,272	8,987,478	13,463,805
5	Malibagh	84207	117	259078	388617	213,200	585,178	798,378	1,197,567
6	Khilgaon	111185	182	1447123	2170685	784,958	1,538,557	2,323,515	3,485,272
Total				6,087,258	9,130,887	7,080,715	14,885,007	21,965,722	32,948,583

All the costs at 2015 prices.

a = based on 260 working days and Peak 6 hours of the day.

b = for peak and off peak hour combined

The total vehicle-our lost in a year (in 260 working days) is 9.13 million. In monetary value the total loss in VOC and VOT combined is 32.95 million USD. The highest loss is suffered at Mogbazar LC with 13.46 million USD in a year. The Mohakhali LC is in the second and Khilgaon LC is in the third position with 9.31 million USD and 3.49 million USD losses in a year respectively. Interesting to mention that, both of these level crossings have flyover passing over them. The flyovers were supposed to reduce the at-grade congestion and reduce the travel time and economic losses. Instead, these two locations suffer more losses than the remaining three LCs. Another flyover is under construction which will pass over the Mogbazar and Malibag flyover. Due to the on-going construction works congestion is high in Mogbazar LC.

The emissions from the vehicles waiting in the queue during the closing period of the level crossing gates have been calculated. Three of the most common and harmful gases emitted from motor vehicles are considered: Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Nitrous Oxides (NOx) are considered in emission cost estimation. Idle vehicle emissions have been considered in the estimation (EPA, 1998). Table 2 summarizes the total emissions in kilograms and their costs for the six level crossings.

Table 2: Emissions and Emission Cost of Studied Level Crossings

Sl.	Location	Annual Emission in Kg			Annual Emission Cost (USD)
		VOC (Volatile Organic Compound)	CO (Carbon Monoxide)	NOx (Nitrous Oxides)	
1	Mohakhali	20470	206519	13989	289,426
2	Truck Stand	1605	28401	1569	36,318
3	Karwan Bazar	16116	287370	19526	378,180
4	Mogbazar	32193	562674	28541	712,683
5	Malibagh	2196	37748	3563	52,828
6	Khilgaon	7744	135840	6064	169,519
Total		80324	1258552	73252	1,638,954

Total yearly emission cost for six level crossings is 1.64 million USD. Emission is highest at Mogbazar LC. That is because the percentage of motorized vehicles are high in this level crossing and also the waiting time and queue length is higher in this level crossing due to the on-going flyover construction. These emissions have serious adverse effect on public health (Krzyżanowski 2005, Künzli et al. 2000, Wjst et al. 1993). Starting from various respiratory diseases these are responsible for cancer if exposed for a long period of time. The emissions not only affect the passengers and riders, but also have severe effect on the people living close to the level crossing junctions. Studies have proven that proximity to traffic sources escalates the risk for asthma and asthma exacerbations on the residents (Salam et al. 2008). As one of them most densely populated urban area in the world the risks are even higher in Dhaka. Specially, at Karwan bazar, Truck Stand, and Khilgaon which have relatively high population density in the surrounding areas compared to the other three level crossings, are more vulnerable to air pollution.

VI. Hazard Index

Hazard index is measured based on New Hampshire equation (equation7) with slight modification. As visibility is an important criteria in urban areas and from the field observation and questionnaire data the visibility was found to be responsible for several collision; this factor is included in this study.

V_f = Visibility factor
= 0.5 for good visibility
= 1 for poor visibility
= 1.25 for very poor visibility.

With V_f the modified equation becomes:

$$HI = (V)\ (T)\ (P_f)\ (V_f) \quad (9)$$

The HI of the studied level crossings is given in Table 3.

Table 3: Hazard Index (HI) of Studied Level Crossings

Grade Crossing	Traffic in PCU/hr[a]	AADT[b]	ADTT	Protection Factor, P_f	Visibility Factor, V_f	HI	DEF	Max. Queue Length (meter)
Mohakhali	3190	79099	90	0.8	1	5695125	7.727	180
Truck Stand	2310	57279	90	0.8	1.25	5155070	6.528	120
Karwan Bazar	3485	86414	90	0.8	1	6221790	7.012	220
Mogbazar	4213	104465	90	0.8	1.25	9401865	6.528	210
Malibagh	3396	84207	90	0.8	1	6062897	7.012	195
Khilgaon	4484	111185	90	0.8	1.25	10006637	7.727	170

a = Traffic volume is the sum of all approaches of the crossing, measured from 10 am to 11 am.
b = Conversion to AADT is done by using expansion factors (Grabber and Hoel, 2014)

[HEF = 17.11, MEF = 1.395, DEF]

As seen from the Table 3, most hazardous location is Khilgaon LC and the least hazardous location among the seven is Truck Stand LC. Both the level crossings have same values of P_f and V_f, but as more road-way traffic passes in the Khilgaon LC it has higher values of HI. Mohakhali LC is the fifth hazardous location among the seven. This is an interesting finding, although Mohakhali and Khilgaon both have flyover running over them which were built to reduce the at grade congestion. Even though, Khilgaon is the most vulnerable location for road way accident. A new flyover Mouchak-Mogbazar flyover is under construction, which will pass over the Mogbazar and Mailbag LC.

The following figure identifies the most vulnerable level crossings in terms of combined value of economic losses and emission costs, and Hazard Index values.

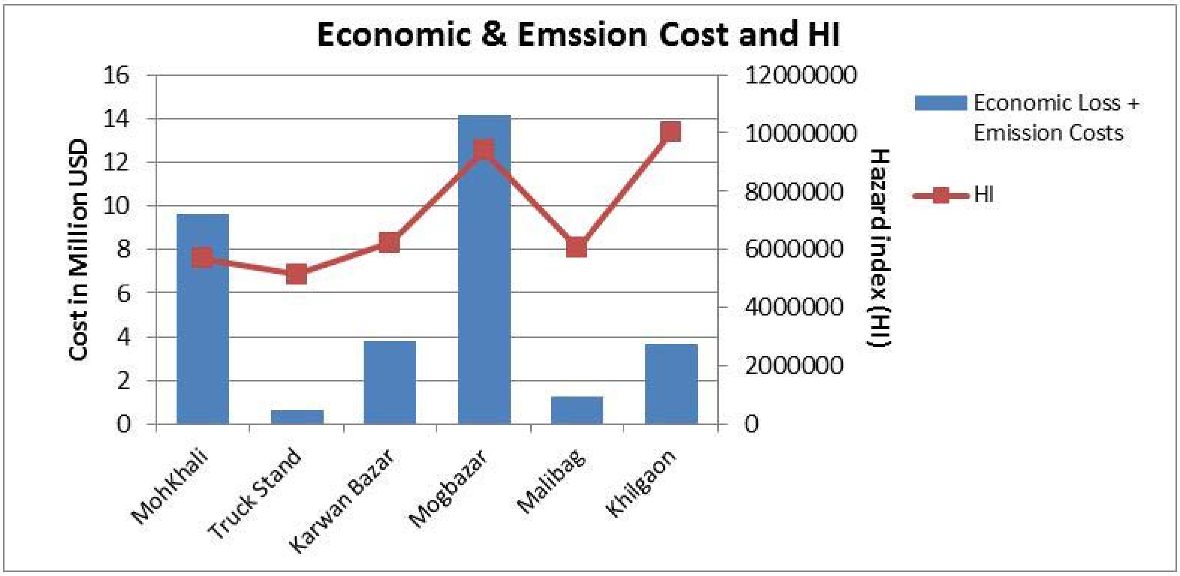

Fig. 2: Economic and Emission Costs and Hazard Index of Level Crossings

The values are high for Mohakhali and Mogbazar LC. As it was mentioned earlier, both of these level crossings have flyover running over them, still these two level crossings suffer the most. The daily vehicle traffic is higher in these locations which also escalates the risk of accidents. At Karwan Bazar and truck Stand LC the visibility is very poor. Slums and shops are located very close to the tracks from Truck Stand to Karwan Bazar LC. At the Mogbazar LC corner plots are occupied by large buildings (Fig. 4).

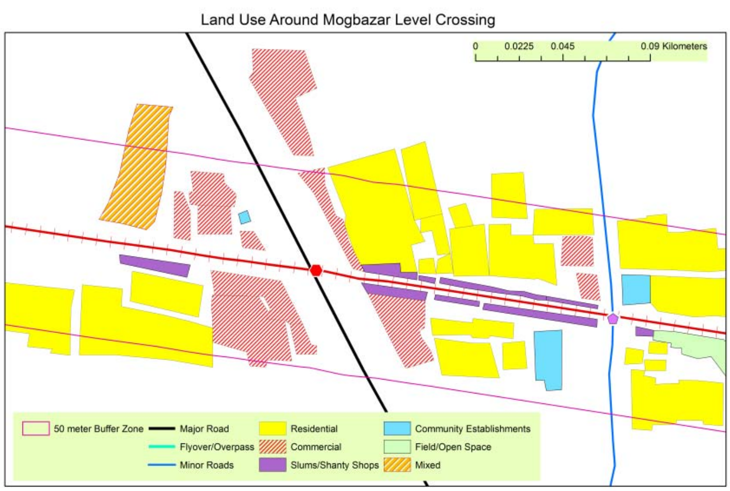

Fig. 4a: Hazardous Level Crossings

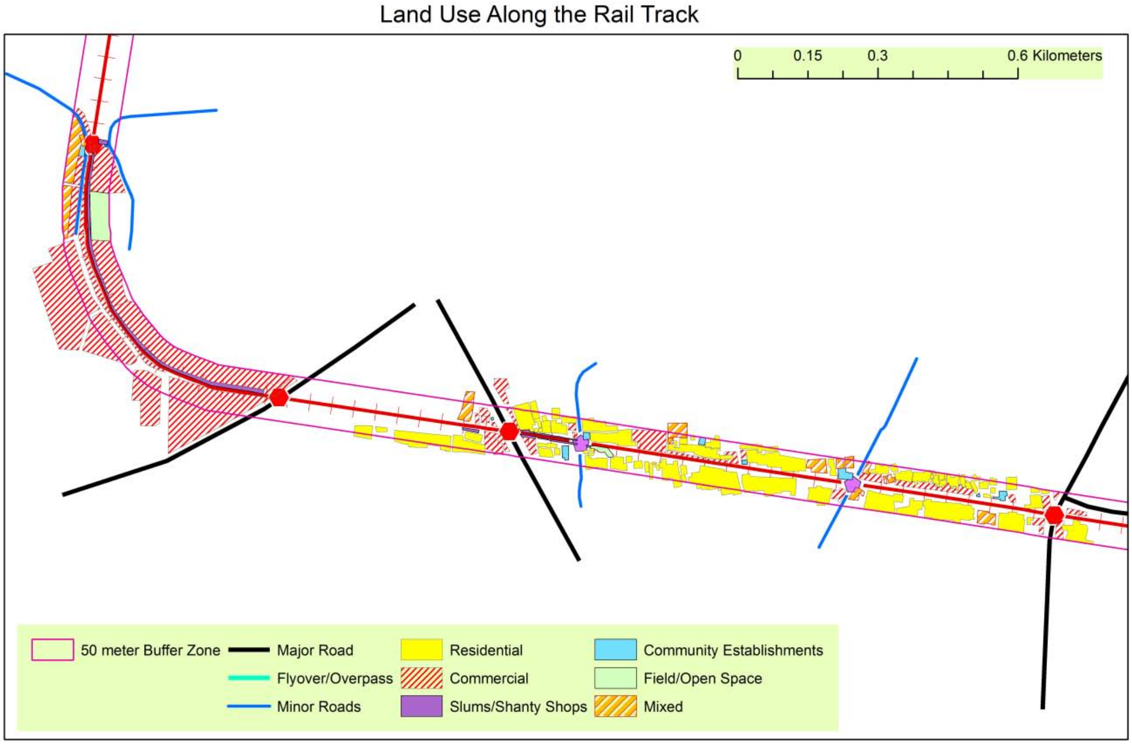

Fig. 4b: Hazardous Level Crossings

In very recent times, several accidents took place in this sort section. Slums and hawkers are also found in the surrounding area of Khilgaon LC. These increase the accident probability in many folds. According to national dailies, 238 people have lost their lives in level crossing related accidents only inside Dhaka city from January 2014 to September 2014. Accident rates are higher for Mogbazar, Karwan Bazar and Khilgaon LC.

VII. Recommendations

To mitigate the congestion and safety problems associated with the grade crossing various countries have adopted, and still adopting the solution of grade separated road-rail crossing. In different countries, different criteria are set to determine the warrant of grade separation. Most widespread parameter defining the need of grade separation is operating speed of trains. Grade separation is warranted if the trains operate at 160 kmph or higher speed (Katz and Guttman, 1991). In Israel the criteria decisive parameter is the product of daily vehicle traffic and the number of trains per crossing per day. These values vary from state to state and lie in the range of 20,000 to 35,000 and 50,000 to 75,000 for a rural and urban crossing respectively (Hakkert and Gitelman, 1997). In India a value of 100000 of this product (known as traffic moment) is used as a threshold to prioritize the sites for grade separation (UNESCAP 2000). In Japan, the criteria for grade separated crossing is set to be product of daily vehicle traffic and the number of hours when the crossing is closed because of trains; if that product exceeds 10,000, the grade separation is warranted (Katz and Guttman, 1991).

Elimination of all the level crossing is the only true way to address the economic losses and the safety issues (VicGov, 2009). It has been suggested to be the most effective measure of ensuring safety and reducing the risk of collision at level crossings (LCSC, 2013). However, due to the built up urban areas elimination of all level crossings altogether may not be feasible. From the analysis, grade separation is warranted for all the 7 level crossings. Following table summarizes the criteria for grade separation used in different countries and the corresponding values for the selected seven level crossings.

Table 4: Grade Separation Criteria for Selected Level Crossings

A= Train Moment*	Israeli Criteria (A ≥ 75,000 for Urban)	Indian Criteria (A ≥ 100,000)	B= Product of Daily Traffic (PCU) and closing time (hr)	Japanese Criteria (B > 10,000)	Train Speed (Kmph)
4,912,281	Y	Y	234701	Y	≤ 30
3,557,169	Y	Y	197601	Y	≤ 30
5,366,552	Y	Y	330937	Y	≤ 30
6,487,599	Y	Y	395203	Y	≤ 30
5,229,500	Y	Y	169959	Y	≤ 30
6,904,912	Y	Y	348813	Y	≤ 30
6,477,030	Y	Y	395819	Y	≤ 30

* *Daily Traffic (PCU) times the Daily No. of Trains*

In terms of vehicular traffic and train traffic, all the level crossings need grade separation as found from Table 4. Although the train velocity is low and thus does not poses any significant threat to the roadway traffic. But again, due to the high roadway traffic and poor methods of gate operation, the trains are compelled to run at a speed lower than the average to avoid any collisions. Thus, this also delays the trains and reduces the efficiency of train movement.

Grade separation is the engineering process of separating roadway traffic modes and railway traffic by way of building a tunnel or a bridge. It reduces road congestion and its bi-products (Guzman et al. 2015). Removal of the level crossing through the construction of a road overpass might have the potential to reduce headways to a significant amount, but in order for the additional line capacity benefits to be realized all other level crossings on the line would also have to be replaced by road overpasses. To adopt this in Dhaka all the level crossing must be replaced by road over-pass or underpass. Installing overpass only in selected locations will not solve the problem as it is evident from the study of Mohakhali and Khilgaon level crossing. While grade separation is the most effective alternative, it is also an extremely costly solution. For example, in Australia, the cost of removing all level crossings in Victoria has been calculated to cost between USD 60 billion and USD 80 billion (NPV) (Lucas, 2009). The Committee for Melbourne estimates USD 100 million per level crossing removal from the Melbourne metropolitan area (CfM, 2011). With 50 years of life time annual cost of a road over-pass is 32.753 Million INR (11.656 Million INR for the year of 2000) or 0.5 Million USD (United Nations ESCAP 2000). Building a crossing grade separation in Israel was estimated to be NIS (New Israeli Sheqel) 2.2 million to NIS 66 million per site. The analogous published estimates for the United States are USD 1.56 million to USD 4.2 million (Rozek et al. 1988) and for Sweden are 3.6 million to 10.8 million Swedish kroner (Asp et al. 1986) (all values converted to 2015 prices).

Automatic barrier is used in many railways (USA, UK, Australia, Germany etc.). With a life time of 15 years the annual cost of an automatic barrier is USD 26,120 (in 2015 price) (United Nations ESCAP 2000). Considering lower cost than grade separation this solution can prove to be useful for Dhaka. With synchronization of the in-train devices the gate closing time can be reduced and accident probability can be minimized.

Several regulatory reforms in the operation of railway can be considered to reduce congestions at the level crossings. A study on the typical railway firm of Japan found some effective regulatory methods to reduce congestion without reducing the firm's cost reducing efforts based on price cap (PC) regulation (Kidokoro 2006). This study, PC regulation with a cap contingent on transportation quality (inverse of congestion rate), was found to relieve congestion without distorting cost-reducing efforts (Kidokoro 2006). The study also found that PC regulation, with fixed investment levels and allowing cost pass-through for investments, can correct the congestion without damaging cost-reducing efforts, ensuring low elasticity of substitution among inputs and proper determination of the target investment levels by the regulator (Kidokoro 2006). Using micro-simulation models, Mitrovik et al. (2012) found that optimizing light rail transit (LRT) schedule with preemption to LRT can reduce at grade congestion. In Dhaka, the railway is operated by Ministry of Railway (MoR) not by any private organization. To learn from Japan, the MoR must conduct a detail study to best meet the demand by reducing congestion in cost-effective way.

Modification of platform arrangements and warning methods can reduce the gate closing time and accident probability. A study by Guzman et al. (2015) proposed that congestion at station level crossings is not caused by the level crossing intersection closure operation, but rather by trains at the platform and/or arriving, forcing the intersection to remain closed for long intervals. At an Arrival Side Platform (ASP) platform,

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a train travelling east to west or up-line, triggers the intersection closure, arriving at the ASP platform before crossing the level crossing intersection, passenger's disembark and board. During this process, the intersection remains closed to all road and pedestrian traffic; the train then proceeds through the level crossing opening the intersection to road traffic. But that is not the case for a Departure Side Platform (DSP). In DSP the passenger boarding and onboarding is done after the train has crossed the level crossing. By installing DSP the congestion can be reduced by a significant amount (Guzman et al. 2015). For the case of Truck Stand LC this method can significantly reduce the gate closing time.

VIII. Conclusions

This study focused on the economic, environmental and safety impact of level crossings inside densely populated urban city. From available methods, simple estimations have been made by minor modification to meet the actual scenario. Field data have been used to estimate the economic losses in terms of VOT and VOC, the environmental effect in terms of emissions and safety threats in terms of Hazard Index. By quantitatively stating all the problems associated with at grade rail crossings, most vulnerable sites have been identified. Also, reviewing the available solutions, some suitable solutions have been proposed in this study.

9.13 million vehicle-hours are lost in a single year in six level crossings. The economic value of lost travel times and vehicle operating cost is 32.95 million USD or 25.62 billion BDT per year. Total yearly emission cost for six level crossings is 1.64 million USD or 1.275 billion BDT per year. Yearly 1412128 kilograms of harmful gases (volatile organic compound, NOx and CO) are emitted during the delays in six level crossings. Khilgaon LC has the highest HI followed by Mogbazar and Karwan Bazar LC.

From all the analysis Mogbazar LC has been identified as the most vulnerable LC as the economic costs, emission values and HI are higher than most of the other level crossings analyzed in this research. Surely, this LC draws the primary attraction for improvement to reduce congestion and economic losses. Mohakhali LC and Khilgaon LC have flyover running over them, but still do not manage to control the congestions to a significant level. Similarly, Mogbazar LC and Malibag LC may face similar consequences as another flyover is under construction in this corridor.

From this study it is obvious that all of the six level crossings require grade separation. But with limited resources and already developed urban establishments this is not the suitable solution for Dhaka. Using automatic barriers, rearrangements of ASP and DSP or adoptions of regulatory measures are some of the recommended solutions.

For staged improvement of the congestion scenario a more detailed research with cost-benefit studies of alternative solution is required. This study has identified the present situation of six level crossings in terms of economic losses and road-rail safety indicators.

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