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Safety Performance of the New Bus Rapid Transit System in Haifa, Israel: First Two-Years of Monitoring

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Abstract

This study explored safety impacts of a new Bus Rapid Transit (BRT) system that was built in the Haifa metropolitan area, Israel, and began its operation in August 2013. Using accident data for Haifa city during the first two-years of the BRT operation, the study examined accident changes on roads with the BRT routes, related to comparison sites, and safety performance of streets with various BRT configurations. In spite of concerns related to the complexity of BRT settings and high traffic volumes, the BRT operation did not lead to a worsening in road safety, while decreasing trends were observed in some accident types and irregular shares of severe or pedestrian accidents did not appear. Such results were judged as successful and supporting the appropriateness of the design solutions adopted in the BRT system. The findings did not indicate significant differences in safety performance of streets with various BRT configurations, thus, leaving space for continued use of various forms. The major safety problem is seen in pedestrian accidents at BRT junctions for which new engineering solutions are needed.

Keywords: safety performance; bus rapid transit; bus route configurations; pedestrian accidents.

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1. Introduction

Public transport priority systems are becoming an attractive solution to improve mobility and promoting public transport use in big cities, throughout the world (ITDP, 2007; Hidalgo and Carrigan, 2010; Panera et al., 2012). The idea of such systems has appeared with the development of Bus Rapid Transit (BRT), originally in South-American countries. Currently, various forms of public transport priority systems, including BRT, can be seen also in India, Mexico, Turkey, Australia, USA and European countries. In Israel, the development of public transport routes for buses is one of the main subjects promoted today by the Ministry of Transport. In the coming years, a rapid development of public transportation is expected in many cities in Israel, including the planning and establishing of hundreds of bus route kilometers. Hence, great importance is assigned today to the examination of planning and safety issues of such systems.

International findings show that the safety level of bus routes depends on the system's characteristics and on the characteristics of streets where they are implemented. Evaluation examples, mostly, from South-American countries and Australia, demonstrated a positive impact of BRT implementation on the safety level of urban roads involved (Duduta et al., 2015a, 2015b). However, in some cases, it was reported that public transport routes' operation was associated with an increase in the number of road accidents whereas pedestrian injury is one of major safety problems in BRT operation (Bocarejo et al., 2012; Duduta et al., 2012, 2015a).

Summaries of international experience provide recommendations for integrating safety in the design and operation of bus routes (TCRP, 2007; Panera et al., 2012; Duduta et al., 2015a; Guide, 2016). The guidelines typically emphasize the need for a physical separation of the bus lanes, highlighting them through a different aggregate color, fencing BRT street segments when applicable, setting signalized intersections only, etc., in order to reduce the interactions between buses and other vehicles and to prevent uncontrolled pedestrian crossings along the bus routes. Over the last two decades, in Israel, substantial efforts were undertaken in adopting the international recommendations for the infrastructure design solutions applied on the new bus routes. Despite that, the introduction of such routes, in some cases, was associated with an increase in accidents, particularly, those involving pedestrians (MOT, 2013).

Being aware of local and international developments, safety issues were of primary importance while a new BRT system was established in the Haifa metropolitan area, in Israel. The BRT system called “Matronit” was built during 2006-2013 and began its operation in August 2013. This system includes lanes and routes with priority and exclusive running for articulated buses (Fig.1). In addition to segregated bus lanes and stops, the BRT system also includes centralized operation control, off-board fare collection, level boarding and other features aimed at increasing operating speeds and service reliability (which typify BRT as indicated, e.g., in Duduta et al., 2015b).

Fig. 1 The BRT bus in Haifa

The BRT network is over 40 km in length, more than half of which belongs to the city of Haifa. The infrastructure design solutions applied in the Haifa BRT system generally followed the recommendations of recent international guidelines mentioned above. At the same time, various configurations of the bus routes were set stemming from the hierarchy of streets in the existing urban network. This study monitored the first two-year safety performance of the BRT system based on road accident data collected for Haifa city. The main purposes of the study were to examine accident changes associated with the introduction of BRT routes on the urban roads and to compare safety performance of streets with various types of BRT arrangements. The study was commissioned by the Yefe Nof Company that supervised the design and construction of the BRT system and is currently responsible for its maintenance and extension, and thus was interested in the examination of the BRT safety impacts. In addition, safety lessons learnt from the Haifa BRT system may be useful for selecting engineering solutions in other bus priority systems, in the country.

2. Literature survey

There is a growing body of literature focusing on public transport and transit systems' safety, while empirical findings on safety impacts of bus priority lanes and BRT are not yet frequent (Goh et al., 2014; Duduta et al., 2015b).

Goh et al. (2014) developed models for predicting bus accidents on road segments with bus service routes, in Melbourne, Australia, and found that accident numbers increase with higher vehicle traffic, bus service frequency and bus stop density, whereas segments with bus priority lanes were associated with lower accident frequency related to those without dedicated bus lanes. This finding was consistent with a previous study conducted in Melbourne (Goh et al., 2013) which showed that the implementation of the Melbourne BRT resulted in an 18% reduction in accidents on streets where the BRT operates.

Tse et al. (2014) examined the safety impacts of bus-lane operation in Hong Kong, using before-after comparisons. On road sections equipped with bus lanes, they found decreasing trends in public bus accidents, of various severity levels, but increasing trends in other vehicle accidents. Most results were not statistically significant but indicated that only buses have benefited in terms of road safety from the bus-lane operation.

Duduta et al. (2015a; 2015b) summarized the experience of the introduction of BRT systems in Guadalajara (Mexico), Bogota (Columbia), and Ahmedabad (India), and reported substantial reductions in fatal, injury and all accidents, at the extent of 30%-50%. The positive safety effects of the BRT remained in place when simultaneous accident reduction trends in the rest of the city were accounted for.

The accident data from BRT systems in South-American countries and India showed (Duduta et al., 2012) that over 90% of accidents occurred outside the dedicated bus lanes and did not involve buses. Hence, the overall safety of bus systems is a matter of infrastructure design solutions and interaction with general vehicle traffic. Pedestrians represented only 7% of the total accidents but over half of fatalities in the bus corridors (Duduta et al., 2012; 2015a). Among typical risky behaviors leading to accidents were: illegal midblock crossings by pedestrians, walking on bus lanes, making a shortcut through traffic lanes from/to a bus stop on the median, running a red light. Preventing pedestrian injury is stated as a primary issue in designing bus priority systems (Duduta et al., 2015a).

The main forms of the bus system configurations, as opposed to conventional mixed traffic, are: center-lane bus-way (or bus corridor), curbside bus lane and counter-flow bus lane. Duduta et al. (2012) adjusted explanatory models for vehicle collisions and pedestrian accidents in the BRT systems in Mexico City, Porto Alegre (Brazil) and Guadalajara. The results showed consistently that center-lane configurations had safety benefits compared to curbside systems, while counter-flow bus lanes were associated with the highest accident rates for both vehicles and pedestrians. Additional model findings showed that higher number of legs at the intersection, higher number of lanes for general traffic and presence of left turns for general traffic at junctions were correlated with higher accident numbers on the bus corridors. Thus, removing traffic lanes, converting four-way junctions into T-junctions and prohibiting left-turns are suggested for improving safety in the BRT systems (Duduta et al., 2015a). Similarly, based on the evaluation results, introducing a central median in the bus corridor and shortening pedestrian crosswalks are suggested for reducing crashes in bus priority systems (Duduta et al., 2015a).

Nevertheless, knowledge of the safety impacts of particular design solutions is not sufficient. For example, in Israel, the common configuration of a bus route is a bus corridor situated in the center of an urban arterial, that is physically separated from other vehicle lanes and, typically, fenced, and includes signalized intersections only. All these features are in line with the best practice recommended by recent guidelines (ITDP, 2007; TCRP, 2007; Duduta et al., 2015a). However, evaluations showed that signalized junctions with bus corridors are characterized by higher numbers of total, severe and pedestrian accidents, relative to comparison-sites without bus corridors, when controlling for other road characteristics (Gitelman et al., 2017). Another local study indicated that junctions with bus corridors (the form mostly advocated in the literature) are associated with higher accident rates compared to junctions with other bus route configurations: center and curbside bus lanes (Gitelman et al., 2015). The higher accident frequency can be explained by higher complexity of traffic arrangements on streets with bus routes as opposed to regular urban arterials. Further research is needed to provide better understanding of the relationships between the design characteristics of bus routes and accident occurrences. In this context, monitoring safety performance of the new BRT system in Haifa might provide new insights into such relationships.

3. Data and Methods

3.1. The Haifa BRT configurations

The Haifa BRT system includes a variety of bus route configurations. For the study examinations, the BRT road sections were subdivided into homogeneous groups, accounting for the road layout, traffic and urban surrounding characteristics, such as: the placement of bus lanes in the road layout (a right or left lane in the carriageway, or a separate center bus corridor); the number of lanes for general vehicle traffic, in addition to BRT lanes; travel directions (one- or two-way directions for BRT and other traffic); type of urban area (built environment, non-built area, industrial zone, city center). In addition, we considered the level of pedestrian activity (none, low, high), junction density (the average distance between junctions below or over 400 m), and exclusive versus combined use of BRT lanes by BRT and other buses. Five groups of bus route configurations were defined, of which four are homogeneous groups and the fifth ("others") includes the rest of segments that did not fit the previous groups. The Haifa BRT configurations are:

- *Center-lane bus-way near two lanes for general traffic* – two-way BRT traffic on both sides of a built median, on a dual-carriageway arterial or collector road. The bus-lane on segments is a left-lane in each carriageway, for an exclusive running of BRT buses (yet, on some segments, the use by regular buses is permitted), segregated by curb and having a red aggregate color, where in the areas of bus stops (near junctions) it becomes a wall-separated bus route. About two thirds of the length of this configuration has high junction density and runs through built environment.
- *Center-lane bus-way near one lane for general traffic* – similar to the previous but situated on collector roads, with one lane for vehicle traffic per direction. Most segments of this configuration have high junction density and are situated in a built environment.
- *Curbside bus lane* - two-way BRT traffic on right-side lanes, on a dual-carriageway arterial or collector road, with two left lanes for general traffic, in each travel direction. The bus-lane is indicated by yellow marking and a red aggregate color and is intended for running of BRT and other buses. Most segments have high junction density and are situated in non-built areas.
- *Counter-flow bus lane* – one-way BRT traffic running against one lane of opposite-direction vehicle traffic. The bus-lane is separated by a marked median, has a red aggregate color and is intended for running of BRT and other buses. All the segments belong to the city center, with high pedestrian activity and high junction density. To prevent severe pedestrian injury, on such streets, the BRT bus speeds were limited to 30 km/h. On other roads, the speed limits of 50 and 70 km/h remained in place for the BRT, similar to general traffic.
- *Others* - includes, mostly, one-way road segments, with left or right bus-lanes near 1-2 lanes of general traffic, and physically separated bus routes. These segments belong mostly to an industrial zone and non-built areas, about half of them with low junction density.

Fig. 2 shows examples of bus lane settings in the Haifa BRT system. Table 1 summarizes the numbers and lengths of the BRT road sections according to the groups, with an indication of those belonging to Haifa city.

a - Center-lane bus-way near 2 traffic lanes b - Curbside bus lane c - Counter-flow bus lane

Fig. 2 Examples of bus lane configurations in Haifa BRT system

3.2. Accident analyses

The safety evaluations in the study dealt with three main issues: (1) an examination of changes in accidents at BRT sites, during the BRT operation versus before periods; (2) monitoring trends in monthly accident series on the BRT routes; (3) a comparative analysis of safety levels of streets with various BRT configurations. *For the first analysis*, odds-ratio estimates with a comparison-group and weighted mean effect were applied (e.g. Gitelman et al., 2014).

As a comparison-group for the BRT sites served the number of accidents in the whole city, similarly to previous studies on the topic (Duduta et al., 2015b). To estimate the safety impact of BRT operation, the number of accidents observed in the "after" period (with BRT at place) at the BRT (or treatment) sites was compared with the number of accidents that would occur in the absence of treatment. The latter is estimated accounting for the accident changes observed, in the after versus before period, in the comparison sites. The evaluation included two steps. First, the safety effect was estimated for each BRT site, where the before and after periods of the comparison-group were matched to the periods of the site examined. Second, a weighted safety effect was estimated for the group of sites with similar BRT configuration. The weighted mean effect (WME) has the form:

$$WME = \exp\left(\frac{\sum_i w_i \ln(\theta_i)}{\sum_i w_i}\right)$$
$$w_i = \frac{1}{VAR(\ln(\theta_i))} = \frac{1}{\frac{1}{X^i{}_a} + \frac{1}{X^i{}_b} + \frac{1}{C^i{}_a} + \frac{1}{C^i{}_b}} \tag{1}$$

where $X^i{}_a$ and $X^i{}_b$ - the numbers of accidents at a BRT site *i*, in the "after" and "before" periods; $C^i{}_a$ and $C^i{}_b$ - the numbers of accidents in comparison-group (for site *i*), in the "after" and "before" periods; θ_i – an odds-ratio estimate for site *i*. (Unequal before and after periods of the treatment site are normalized in the odds-ratio by using the same time periods for the comparison sites.) The confidence interval of WME is given by:

$$\left(WME \times \exp\left(\frac{z_{\frac{\alpha}{2}}}{\sqrt{\sum_i w_i}}\right), WME \times \exp\left(\frac{z_{1-\frac{\alpha}{2}}}{\sqrt{\sum_i w_i}}\right) \right) \tag{2}$$

The accident reduction is significant when the whole WME confidence interval is below one. Where it includes one, the result is not significant but a decreasing or increasing accident trend can be indicated depending on the WME-value. The safety effect is reported in percent and is calculated as (1-WME)*100.

Table 1. BRT road sections by bus-lane configuration groups, with the total number of accidents observed, during 24 months of BRT operation and in the before periods, in Haifa city.

				Accidents on road sections, in Haifa				Accidents at junctions, in Haifa			
Group by bus route configuration	No of road sections (of which in Haifa)	Total length, km (of which in Haifa)	Period*	Total injury	Severe	With pedestrians	With buses	Total injury	Severe	With pedestrians	With buses
G1 Center-lane bus-way near 2 lanes	13 (9)	17.4 (6.6)	b	167	32	41	4	254	26	35	3
			a	23	5	4	2	95	6	18	7
G2 Center-lane bus-way near one lane	4 (3)	2.2 (1.2)	b	22	6	11	0	27	2	11	1
			a	3	1	0	1	5	0	3	0
G3 Curbside bus lane	2 (2)	6.9 (6.9)	b	13	5	2	1	60	10	10	0
			a	15	2	3	0	38	5	7	1
G4 Counter-flow bus lane	4 (4)	2.3 (2.3)	b	11	2	6	0	48	4	13	1
			a	7	2	6	1	28	6	10	8
G5 Others	18 (18)	7.4 (7.4)	b	47	7	10	2	105	16	41	1
			a	13	1	8	3	46	5	11	7

**b* –before, *a* - after

For each BRT site, detailed information on the period of reconstruction (between 2006 and 2013) was collected, and then before and after periods were defined. The "after" period of 24 months, from August 2013 till July 2015, was considered for all BRT sites, whereas the "before" period moved depending on actual roadworks but typically comprised three years. The accident data were extracted from the Haifa municipality accident database, which is a refined data source compared to the national accident files due to additional verifications versus the original police files that are imposed on the data. (Such improved data are unavailable for other towns in the Haifa metropolitan area and thus, only Haifa city BRT sites were included in the analysis). The analyses referred separately to road sections and intersections and included total injury accidents and the subtotals of severe (fatal and serious), pedestrian and bus accidents. Table 1 provides the total number of accidents observed, during the BRT operation and in the before periods, on the BRT sites in Haifa city.

For the second analysis, Poisson regression models with time as a linear explanatory variable were fitted to the monthly time-series of accident numbers on the BRT sites and comparison sites, in the 24 months of BRT operation. The models had the form of:

$$\lambda = e^{\alpha+\beta\cdot time} \tag{3}$$

where: λ - monthly accident expectancy; *time* – months; α, β - model coefficients. The models were fitted using GLM function of *R*. (To satisfy a Poisson distribution, data transformations were applied). As comparison sites at this step were selected road sections from Haifa city, with road layouts and traffic levels similar to the BRT road sections but without dedicated bus lanes. In total, 135 road sections and 269 junctions composed the comparison-groups, where dual-carriageway streets with two lanes per direction served as comparison sites for BRT groups *G1, G3* (see Table 1); dual-carriageway streets with one lane per direction served as comparison sites for BRT group *G2*; single-carriageway streets – for BRT group *G4*, and all comparison sites together – for BRT group *G5* and for all BRT sites together. When β (slope) in eq. (3) is significant, an over-time trend is found in the series examined. The slopes of the trend lines, during the period of the BRT operation, were compared between the BRT and comparison sites, using a *T-test* statistic.

For the third analysis, the BRT sites of groups *G1-G4* were characterized in terms of traffic volumes of general vehicle traffic, BRT buses, all buses together and the level of crossing pedestrian activity. The numbers were extracted from available traffic counts at the BRT junctions and then classified into five categories, from low to high, for each type of traffic. In addition, the types of junctions (signalized or not) were indicated. To ascertain the impact on accident occurrences of BRT configurations and other features, explanatory models were fitted to the number of accidents at the BRT sites, during the BRT operation period, using MANOVA (Multivariate Analysis of Variance) models (Tabachnik and Fidell, 2006). MANOVA presents an extension of the univariate analysis of variance, where it tests the hypothesis that one or more independent variables have an effect on a set of two or more dependent variables (various accidents types, in our case).

4. Results and discussion

In the first two-years of the BRT operation, in total, 61 injury accidents occurred on the BRT road sections and 212 injury accidents – on the BRT junctions (in Haifa city, see Table 1). The total numbers of severe accidents were 11 and 22, respectively, the numbers of pedestrian accidents – 21 and 49. The overall shares of severe and pedestrian accidents on the BRT streets (12% and 21%) were not exceptional but similar to the average shares of such accidents on urban roads in Israel. In total, 7 accidents involving buses occurred on the BRT road sections and 23 – at the BRT junctions, half of them were with the BRT buses. Accounting for both high traffic volumes and high frequency of bus services on the BRT lanes, the numbers of accidents observed in the BRT system was not high.

4.1. After-before comparisons

Table 2 shows a summary of accident changes observed at the BRT sites, during the BRT operation versus "before" periods and related to changes occurred in the comparison-group sites. (Accident types with insufficient data – below 10, in before and after periods together, were not estimated.) The results indicate that the new BRT operation was associated with mixed accident trends. On streets with center-lane bus-way (*G1-G2*) and *others* configurations (*G5*) decreasing accident trends were observed in total accidents on road sections, while on sections with curbside bus lane an increasing trend was found (and no change on sections with counter-flow bus lanes). It seems that a center-lane configuration reduces the interaction of BRT with other vehicle traffic, on road sections, thus diminishing the risk of accidents. In contrast, a curbside configuration does not prevent vehicles to enter the bus lane, e.g. of those who need to stop near a sidewalk or preparing to turn, and therefore, a higher frequency of bus services following the BRT introduction, may increase the accident occurrences.

On most BRT configurations (except for total accidents in *G2* and severe and pedestrian accidents in *G5*), increasing accident trends were observed at junctions. A possible reason for that can be the higher complexity of traffic arrangements at junctions including BRT lanes compared to regular urban intersections.

Pedestrian accidents showed decreasing trends on sections with center-lane bus-way that can be related to the presence of raised medians with obstacles and fences preventing uncontrolled pedestrian crossings. An increasing trend in pedestrian accidents was observed on streets with counter-flow bus lanes that can be expected due to high pedestrian activity on these streets, which were reconstructed for the BRT operation, belong to city center and incorporate plenty of commerce and business uses.

In all BRT groups, except for *G5* (with lower pedestrian presence), increasing trends were found in pedestrian accidents at junctions. Such a result is expected due to higher complexity of crosswalk arrangements at junctions with BRT lanes and longer waiting time for pedestrians, particularly on dual-carriageway roads with high traffic volumes. This problem was also raised by previous studies of BRT safety in Israel (Gitelman et al., 2015; 2017). However, most accident changes during the BRT operation were not significant and the amount of severe accidents was not high, indicating that the Haifa BRT introduction did not cause a substantial worsening in road safety as it happened in local experience with some previous projects of introducing bus priority lanes (MOT, 2013).

Table 2. Accident changes observed at the BRT sites, during 24 months of BRT operation.

Accident type	Weighted mean effect	95% Confidence Interval		Meaning
	G1 Center-lane bus-way near 2 lanes			
Severe accidents, on sections	0%	-67%	199%	No change
Total injury accidents, on sections	-37%	-62%	2%	Decreasing trend
Pedestrian accidents, on sections	-28%	-80%	163%	Decreasing trend
Severe accidents, at junctions	23%	-63%	308%	Increasing trend
Total injury accidents, at junctions	43%	10%	86%	Increase
Pedestrian accidents, at junctions	141%	14%	407%	Increase
	G2 Center-lane bus-way near one lane			
Total injury accidents, on sections	-70%	-95%	94%	Decreasing trend
Pedestrian accidents, on sections	-94%	-100%	234%	Decreasing trend
Total injury accidents, at junctions	-31%	-74%	83%	Decreasing trend
Pedestrian accidents, at junctions	54%	-66%	608%	Increasing trend
	G3 Curbside bus lane			
Total injury accidents, on sections	52%	-29%	223%	Increasing trend
Severe accidents, at junctions	-6%	-71%	201%	Decreasing trend
Total injury accidents, at junctions	26%	-18%	92%	Increasing trend
Pedestrian accidents, at junctions	30%	-52%	251%	Increasing trend
	G4 Counter-flow bus lane			
Total injury accidents, on sections	-3%	-64%	162%	No change
Pedestrian accidents, on sections	21%	-69%	363%	Increasing trend
Severe accidents, at junctions	215%	-23%	1192%	Increasing trend
Total injury accidents, at junctions	39%	-16%	130%	Increasing trend
Pedestrian accidents, at junctions	45%	-42%	259%	Increasing trend
	G5 Others			
Total injury accidents, on sections	-31%	-65%	37%	Decreasing trend
Pedestrian accidents, on sections	9%	-64%	226%	Increasing trend
Severe accidents, at junctions	-29%	-79%	147%	Decreasing trend
Total injury accidents, at junctions	10%	-24%	60%	Increasing trend
Pedestrian accidents, at junctions	-21%	-62%	66%	Decreasing trend

4.2. Monthly accident trends during BRT operation

Table 3 presents a summary of slopes of the trend lines in monthly accident series at the BRT and comparison sites. (The models were fitted to cases where the number of months with accidents, during the BRT operation, was over eight.) The findings show that monthly series of total injury accidents on the BRT routes mostly indicated a decreasing trend over the BRT operation period, where some of them were significant, yet, no differences (in slopes) related to the comparison streets were ascertained. A close to significant difference, with p<0.1, was found in one case - in total injury accidents at junctions, where a decreasing trend on BRT streets with center-lane bus-way near two lanes (*G1* group) was stronger than on comparison streets. This case is presented in Fig.3. In the numbers of pedestrian accidents at the BRT sites increasing trends were observed over the BRT operation period but not significant, while at the comparison sites mixed trends were indicated (also, not significant). In general, accident trends at the BRT sites, during the first two-years of its operation, were positive, indicating a slight over-time decrease in accident occurrences. However, further attention is required to pedestrian accidents, which demonstrated signs of increasing trends.

Table 3. Slopes of the trend lines in monthly accident series at the BRT and comparison sites.

Accident type	Group of BRT sections	On BRT streets	On comparison streets
Total injury accidents, on sections	G1	0.0344	0.0041
	G3	-0.0146	-0.0073
	G5	-0.0137	-0.0239*
	All	-0.0016	-0.0239*
Total injury accidents, at junctions	G1$^{\#}$	-0.0391**	-0.0059
	G3	-0.0299	-0.0064
	G4	-0.0037	0.0089
	G5	0.0009	-0.0049
	All	-0.0235**	-0.0049
Pedestrian accidents, on sections	All	0.0425	0.0163
Pedestrian accidents, at junctions	G1	0.0035	-0.0087
	All	0.0021	0.0026

Significant with *p<0.1, **p<0.05. $^{\#}$ Significant difference in slopes, with p<0.1, between BRT and comparison sites.

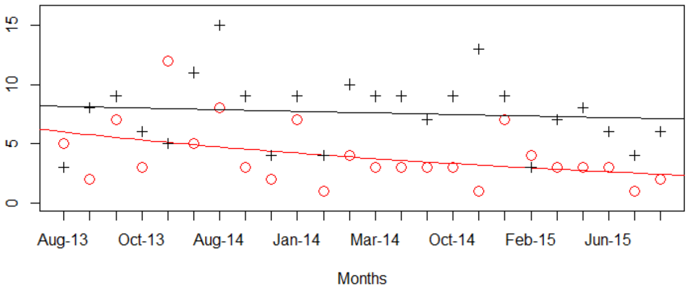

Fig.3 Monthly numbers and trend lines of total injury accidents, at BRT junctions (in red) and comparison sites (in black), for *G1* configuration of bus-lanes

4.3. Factors associated with accident occurrences at the BRT sites

At this step, we explored the impact of traffic and road layout characteristics on accident occurrences at the BRT sites. Table 4 presents the mean values of characteristics of the BRT junctions, in four groups according to bus route configuration. (Group *G5* was excluded from this analysis due to the heterogeneous layouts of bus-lanes.) The values in Table 4 indicate that higher frequencies of both total and pedestrian accidents refer to *G1* junctions, with center-lane bus-way near two lanes of general traffic, similar to findings of another local study (Gitelman et al., 2015). Higher numbers of total and severe accidents were also observed at junctions with curbside bus-lanes (*G3*). Both groups are characterized by higher levels of traffic volumes and *G1* – by higher frequency of BRT service, that may lead to higher accident numbers.

Table 5 presents the explanatory models adjusted to the number of total and pedestrian accidents that occurred at the BRT junctions, during the BRT operation period. The models showed that bus route configurations did not have a significant impact on accident occurrence. At the same time, more accidents of both types are expected at junctions with higher levels of general vehicle traffic, bus and BRT traffic together and crossing pedestrians, where a higher level of BRT traffic (only) has a moderating effect on accidents.

Table 4. Characteristics of BRT junctions, in groups of bus route configuration (mean values per junction).

Group	No of junctions (of which un-signalized)	Total injury accidents per junction[#]	Severe accidents per junction[#]	Pedestrian accidents per junction[#]	Total vehicle traffic[*]	BRT traffic[**]	BRT and bus traffic together[***]	Crossing pedestrian activity[&]
G1	26 (3)	3.65	0.23	0.69	3.8	3.7	2.2	2.3
G2	6 (0)	0.83	0	0.5	1.5	3.3	3.2	3.3
G3	13 (4)	2.92	0.38	0.54	3.8	3	3.2	1.7
G4	19 (0)	1.47	0.32	0.53	1	1	1	4.5

Notes to Table 4: the un-signalized junctions are right-turn junctions, without crossing traffic on the main road. [#]in two years of BRT operation. [*]According to 5 categories: (1) up to 10; (2) 10-20; (3) 20-30; (4) 30-40; (5) over 40 (thousands of vehicles). [**]According to 5 categories: (1) 104; (2) 208; (3) 328; (4) 518; (5) 726 (BRT buses). [***]According to 5 categories: (1) up to 0.75; (2) 0.75-1; (3) 1-1.25; (4) 1.25-1.5; (5) over 1.5 (thousands of buses). All traffic counts in 14 hours, between hours 6-20, in both travel directions of the main road. [&]According to categories: (0) no crosswalks; (1) very low; (2) low; (3) medium; (4) high; (5) very high.

Table 5. Explanatory models to total and pedestrian accident numbers, at the BRT junctions.

a – Dependent variable: total injury accidents

Parameter	B	Std. Error	t	Sig.
Intercept	-4.45	1.95	-2.28	0.027
Total vehicle traffic	2.64	0.93	2.84	0.006
BRT traffic	-2.23	0.80	-2.79	0.007
BRT and bus traffic together	1.00	0.45	2.22	0.031
Crossing pedestrian activity	0.93	0.45	2.06	0.045
Signalized junction	0.30	1.63	0.18	0.855
G1	1.69	1.75	0.96	0.339
G2	2.18	1.84	1.18	0.242
G3	-1.03	2.03	-0.51	0.614
G4	0[*]	.	.	.

b – Dependent variable: pedestrian accidents

Parameter	B	Std. Error	t	Sig.
Intercept	-1.86	0.77	-2.42	0.019
Total vehicle traffic	0.76	0.37	2.09	0.041
BRT traffic	-0.60	0.31	-1.90	0.063
BRT and bus traffic together	0.31	0.18	1.72	0.090
Crossing pedestrian activity	0.60	0.18	3.35	0.001
Signalized junction	-0.79	0.64	-1.23	0.223
G1	0.48	0.69	0.70	0.487
G2	1.03	0.73	1.42	0.161
G3	-0.18	0.80	-0.23	0.823
G4	0[*]	.	.	.

[*]A reference group. Model statistics: (a) $F_{(8,55)}$=3.29, p=0.004, variance explained 22.5%; (b) $F_{(8,55)}$=2.06, p=0.056, variance explained 11.8%.

5. Conclusions

International research provided examples of accident reductions associated with BRT implementation on urban roads but also reported cases of an increase in accidents indicating a particular risk of pedestrian injury related to BRT operation (Duduta et al., 2015a, 2015b). Previous local experience showed that urban streets with bus priority routes frequently had worse safety records compared to other streets, due to higher complexity of traffic arrangements on such streets (MOT, 2013; Gitelman et al., 2015; 2017). Hence, an increase in accidents during the initial BRT operation could be expected. However, during the first two-year operation of the new BRT system in Haifa a substantial worsening in road safety was not found but mixed accident changes were observed. In after-before comparisons, the BRT sections with center-lane bus-ways showed decreasing trends, while for curbside and counter-flow bus lanes increasing trends were observed. On most BRT configurations, increasing accident trends were observed at junctions, particularly in pedestrian accidents. At the same time, most after-before accident changes were not significant. The monthly time-series of accidents during the BRT operation indicated a slight over-time decrease in total accidents (significant at junctions) but an increasing trend in pedestrian accidents (insignificant). Overall, the BRT operation was not associated with high accident numbers or irregular shares of severe or pedestrian accidents, compared to other urban streets. Such results can be judged as successful and supporting the appropriateness of the design solutions adopted in the new BRT system.

The models did not indicate significant differences in safety performance of streets with various BRT configurations, thus, leaving space for continued use of various forms. In general, sections with center-lane bus-ways and, particularly those having one traffic lane, demonstrated lower risk of accidents, that is in line with international experience (Duduta et al., 2012; 2015a). In spite of concerns in the literature, streets with counter-flow bus lanes did not experience high accident frequencies, apparently, due to lower speed limits (30 km/h) imposed on the BRT buses on such streets. For most BRT configurations, the major safety problem should be seen in pedestrian accidents at BRT junctions for which new engineering solutions are needed.

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