Safety performance of the new BRT system in Haifa, Israel

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Extended abstract

Introduction

Public transport priority systems are becoming an attractive solution to improve mobility and promoting public transport use in big cities, throughout the world. 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, European and other 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 routes 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 it is implemented. Evaluation examples, mostly, from South-American countries, demonstrated a positive impact of BRT implementation on the safety level of urban roads involved. However, in other cases, the public transport routes' operation was associated with an increase in the number of road accidents [1-2]. Summaries of international experience provide recommendations for integrating safety in the design and operation of bus routes [2-4]; however, sufficient details with regard to safety impacts of various design solutions are generally lacking. Moreover, over the last decades, the infrastructure design solutions applied on the bus routes in Israeli cities, typically followed international recommendations. Despite that, the introduction of such routes, not once, was associated in local experience with an increase in accidents, particularly, involving pedestrians [5].

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 in 2006-2013 and began its operation in August 2013. This system includes lanes and routes with priority and exclusive running for articulated buses. 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 new BRT system were in line with recommendations of recent guidelines, with preferably physical separation of the BRT lanes, pedestrian fencing when applicable and signalized intersections only. This study examined the first two-year safety performance of the BRT system based on road accident data collected for Haifa city.

Data and Methods

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; the number of lanes for general vehicle traffic; travel directions; type of area (built environment, unbuilt area, industrial zone, city center); level of pedestrian activity; junction density; and exclusive versus combined use of BRT lanes by BRT and other buses. Five groups of bus route configurations were defined, which are center-lane bus-way near two lanes for general traffic; center-lane bus-way near one lane; curbside bus lane; counter-flow bus lane and *others* (the latter includes, mostly, one-way roads and physically separated bus routes). Figure 1 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 indication of those belonging to Haifa city.

The safety evaluations dealt with three main issues: (1) an examination of changes in accidents on the streets with BRT lanes, during the BRT operation versus before periods; (2) monitoring of 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, a common method of odds-ratio estimates with a comparison-group and weighted mean effect was applied [6], where as a comparison-group served the number of accidents in the whole city. For each BRT road section, detailed information on the period of reconstruction was collected, and accident data were matched, respectively, for the before and after periods, at the BRT and comparison sites. The "after" period of 24 months, from August 2013 till July 2015, was considered for all BRT sites, whereas the "before" period was different depending on actual roadworks but typically comprised three years. The analyses referred separately to road section and intersection accidents and included total injury accidents and the subtotals of severe, 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.

a - Center-lane bus-way   b - Curbside bus lane   c - Counter-flow bus lane

Figure 1. Examples of bus lane configurations in Haifa BRT system.

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

Group by bus route configuration	No of road sections (of which in Haifa)	Total length, km (of which in Haifa)	Period*	Accidents on road sections, in Haifa				Accidents at junctions, in Haifa			
				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 the second analysis, Poisson regression models were fitted to the monthly time-series of accident numbers on the BRT sites and comparison-group sites, in the form of:

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

where: λ - the number of accidents expected; α, β - model coefficients. When β (slope) is significant, an over-time trend is found in the series examined. As comparison-group sites at this step were selected street sections from Haifa city, with road layouts and traffic levels similar to the BRT road sections but without dedicated bus lanes. The slopes of the trend lines, during the period of the BRT operation, were compared between the BRT and comparison-group 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 vehicles, bus and BRT vehicles together and the level of crossing pedestrians. 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 lengths of road sections and 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 [7]. (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).

Results

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[1].

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

[1] 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 most BRT configurations, increasing accident trends were observed at junctions. At the same time, on streets with center-lane bus-way and *others* configurations (*G1*-*G2* and *G5*) decreasing accident trends were observed on road sections. In all BRT groups except for *G5*, increasing trends were found in pedestrian accidents at junctions. However, most accident changes during the BRT operation were not significant.

Table 3 presents a summary of slopes of the trend lines in monthly accident series at the BRT and comparison-group sites[2]. The findings show that monthly accident series 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 only - in total injury accidents at junctions, where a decreasing trend on BRT sections of *G1* group was stronger than on comparison sections). In the numbers of pedestrian accidents at the BRT sites increasing trends were observed over the BRT operation period but not significant.

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 sections	On comparison sections
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.

Table 4 presents the explanatory models adjusted to the number of total injury 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.

Conclusions

Previous experience showed that urban streets with bus priority routes frequently had worse safety records compared to other streets, due to a higher complexity of traffic arrangements on such streets [2,5]. Hence, an increase in accidents during the initial BRT operations can be expected. However, during the first two-year operations of the new BRT system in Haifa a substantial worsening in road safety was not found and even decreasing trends were observed in some accident types. Such results can be judged as successful and supporting the appropriateness of the design solutions adopted in the new 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 should be seen in pedestrian accidents at BRT junctions for which new engineering solutions are needed.

[2] The models were fitted to cases where the number of months with accidents, during the BRT operation, was over 8.

Table 4. Explanatory models fitted to total injury and pedestrian accident numbers, at the BRT junctions, during BRT operation period

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
Traffic of crossing pedestrians	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
Traffic of crossing pedestrians	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%.

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