Palacký University Olomouc

Transactions on Transport Sciences
Peer-Reviewed Open Access Journal
Vol. 3/2021 DOI: 10.5507/tots.2021.023
journal homepage: www.tots.upol.cz

Exploring the safety level of a signalized roundabout with crossing BRT: an observational pilot, in Israel

VICTORIA GITELMAN, ANNA KORCHATOV

Transportation Research Institute, Technion City, Haifa, Israel 32000

ABSTRACT: Bus rapid transit (BRT) systems promote public transport use in big cities, but their implementation requires substantial changes in urban infrastructure, with impacts on road user behaviours and safety. In Israel, recently, a BRT system called "Matronit" was introduced in the Haifa metropolitan area. The extension of the BRT network included a new setting - a signalized multi-lane roundabout with a bi-directional BRT running through its center and traffic lights for the circular traffic when crossing the BRT route. Such a setting was not familiar to Israeli drivers and thus the initial operation of the roundabout was accompanied by an observational pilot. The study focused on safety-related behaviours of road users, e.g. drivers' compliance to the red-light; vehicle behaviours in the roundabout entrance areas; giving right-of-way to pedestrians. A before-after comparison was not possible, thus, the study aimed to characterize the safety level of the new setting by estimating the rates of risky behaviours observed and comparing them with indicators reported in the literature for similar traffic settings. The data were extracted from video-records of the traffic control center, in four areas of the roundabout, two near the traffic lights and at two entrance areas. The results showed that red-light violations were committed by 14% of the vehicles in one traffic-light area, with no cases in the other. On average, one-two red-light violations can be expected per hour, the frequency comparable with signalized intersections. Furthermore, 86% of the cases occurred during the first two seconds of the red-light, with no "near-collisions" between the vehicle and the BRT. In both entrance areas, when traffic was present inside the roundabout, 10%-20% of entering vehicles did not slow down, and this behaviour was more frequent under the red-lights. However, in most cases, the distance between the interacting vehicles was sufficient, while conflicts (with braking) were rare, in 1% of cases. Pedestrian appearance on the crosswalks was rare, but many of them (38%) were ignored by entering vehicles, while such behaviour is common for multi-lane roundabouts. In summary, the pilot demonstrated that the safety level of the roundabout was comparable to other settings, but risky driver behaviours were present both near the traffic lights and in the entrance areas. The findings seem to be site-specific and further research is needed to better fit infrastructure design solutions to various traffic volumes at roundabouts with crossing BRT.

KEYWORDS: BRT priority; signalized roundabout; red-light compliance; driver behaviours; observations

1. INTRODUCTION

Current policies for sustainable urban mobility focus on promoting public transport, walking and cycling (Winters et al., 2017; Rupprecht Consult, 2019; Paganelli, 2020). Bus priority systems are a common solution to promote public transport (PT) use in big cities (TCRP, 2007; Duduta et al., 2015; ITDP, 2017). Bus priority systems include various forms of priority for bus traffic such as bus routes, bus priority lanes and bus rapid transit (BRT). A bus route is typically defined as a facility providing a physical separation of PT paths from the general traffic lanes, to enable higher operating speeds for PT. Bus priority lanes allow a broader range of road layouts (for example, curbside, median-side, etc.) and traffic management solutions (for example, full-time or part-time, exclusive or mixed use, etc.). Beside physical separation from other traffic lanes, various forms of signal priority at intersections can be introduced as well. A BRT is considered as the ultimate form of bus priority; BRT is defined as an integrated system combining infrastructure facilities for the exclusive bus running together with components of an intelligent management system and services such as centralized operation control, off-board fare collection and level boarding (TCRP, 2007; Duduta et al., 2015). Currently, various forms of BRT systems can be met in such countries as Brazil, Colombia, India, Turkey, China, Australia, USA and in some European countries.

The implementation of bus priority systems and BRT, in particular, requires substantial changes in urban road infrastructure, to enable bus running priorities on the traffic routes. Beside the evident improvement of PT services, e.g. in terms of reduced passenger travel time and better reliability and attractiveness of public transport (e.g. Hidalgo et al., 2013; Ingvardson and Nielsen, 2018), the impacts of bus priority systems' and BRT infrastructure changes on traffic safety can be mixed, with a possible increase in traffic injury of other road users, e.g. vehicles and pedestrians (Duduta et al., 2015; Gitelman et al., 2020). One of the reasons for that lies in the fact that the infrastructure settings with an exclusive or priority run of buses are typically more complex than traditional urban settings, thus imposing additional demands on road user behaviours, particularly at intersections. However, available evidence on the safety impacts of bus priority systems and BRT infrastructure solutions is not extensive, indicating a need for more empirical research (Vecino-Ortiz and Hyder, 2015; Gitelman et al., 2020).

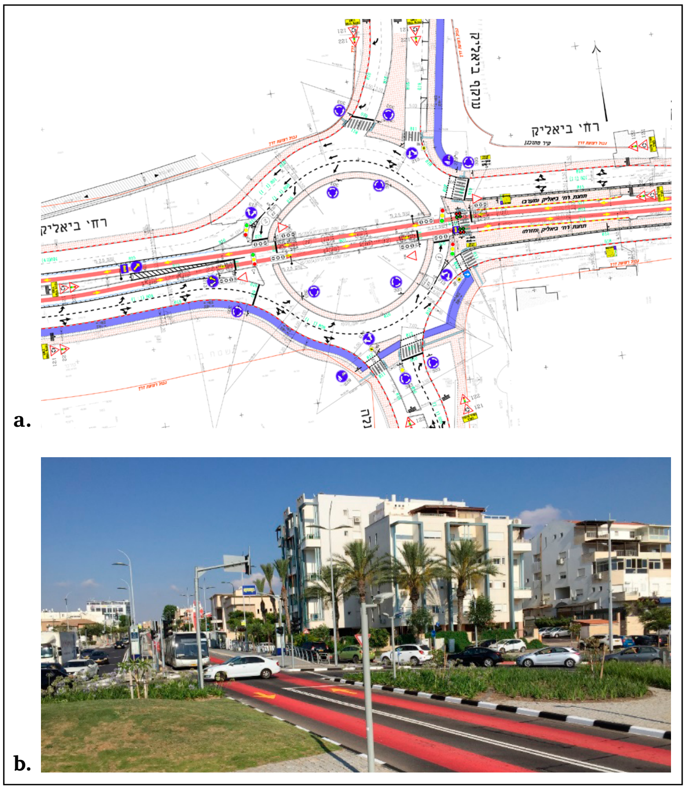
In Israel, the development of bus priority systems is one of the main policies promoted today by the Ministry of Transport (MOT, 2012; Planning Administration, 2020). Recently, a new BRT system called "Matronit" was introduced in the Haifa metropolitan area, in the north of the country, and over the last years, hundreds of bus priority kilometers are being planned in many cities, in all country areas. The "Matronit" BRT system comprises over 40 km of bus priority routes for the operation of articulated buses; the BRT routes are indicated by red-color aggregate. The system includes various forms of bus route configurations on road sections and at signalized intersections, of which safety impacts were explored by previous research studies (Gitelman et al., 2018; 2020). It can be noted here that according to Israeli experience, bus priority systems on busy urban roads may increase accidents, and thus, following a BRT introduction, negative safety implications can be expected, in general. However, unlike other local cases, the BRT experience in Haifa demonstrated that negative safety impacts can be moderated due to a wider use of safety-related measures and a proper fit of bus route configurations. The after-before comparisons showed that, in the initial period of the BRT operation in Haifa, increasing accident trends were observed in many accident types, but they weakened or even became decreasing trends in the longer term, after two years of the BRT operation. Median-side BRT configurations were found to be safer than curbside; the best safety level was found for a center-lane BRT near a single lane for all-purpose traffic.

A further extension of the BRT network in the Haifa metropolitan area planned to include a new setting - a signalized multi-lane roundabout with a bi-directional BRT running through its center and traffic lights installed at the points where the circular traffic crosses the BRT route - Figure 1. Such a traffic arrangement was not familiar to Israeli drivers. Hence, the transport authorities raised concerns regarding its safety. First, there was concern about incompliance with traffic lights by vehicles traveling in the roundabout, which could lead to collisions between vehicles and the BRT. In addition, there was concern about drivers not understanding the new arrangement, that could cause dangerous situations while entering or passing through the roundabout.

Throughout the world, there is experience of roundabouts with traffic lights and/or giving priority to a BRT crossing; for instance, examples of signalized roundabouts with crossing bus (or tram) routes can be found in various cities in Europe (Finn et al., 2011; Fontaine et al., 2015). It is noted that a regular roundabout has disadvantages for public transport crossing it, such as a lack of PT priority at the entrance to the roundabout, more difficult entry maneuvering for long vehicles, and inconvenience to bus passengers when moving in the circle. Thus, a direct crossing of the roundabout by PT was suggested. Nonetheless, in the professional literature, there is little information about the effects of this type of arrangement on driver behaviours and safety. Therefore, the Ministry of Transport in Israel decided to conduct a pilot that would include an initial operation of the setting, at one site, and be accompanied by an observational study. The study aimed to examine the new setting's impact on driver behaviours with respect to road safety. The pilot intended to explore whether the traffic setting is understandable to drivers and they behave as expected, and to verify that the new arrangement is not associated with increased safety risks for the road users.

1.1 Previous literature on the related topics

As noted above, using roundabouts with traffic lights and giving priority to a BRT crossing is known in the international experience. For example, the Institute for Transportation and Development Policy' Guide (ITDP, 2017) describes different arrangements of BRT lanes in a roundabout and indicates that an exclusive lane for BRT crossing a roundabout requires traffic lights. Finn et al. (2011) surveyed traffic settings in systems with "buses with high level of service" in Europe, and found that in many cities in France and Sweden, e.g. Nantes, Lorient, Jonkoping, Gothenburg, the infrastructure solutions implemented involved a direct crossing of the roundabout by PT. As reported, such settings are effective in giving priority to PT in roundabouts. However, it is still necessary to address safety issues because of the increased complexity of such arrangements, especially at large roundabouts where vehicle speeds may be higher.



Notes: The BRT route is indicated in red. The traffic lights' area of the roundabout, a BRT vehicle and the bus stop, near the roundabout, can be seen in the bottom picture.

Figure 1. The signalized roundabout with crossing BRT: (a) general plan; (b) a view to east direction from inside the roundabout.

Brilon (2011) reviewed traffic arrangements of roundabouts in Germany and noted that a roundabout crossed by a central PT lane will function as a normal roundabout as long as there is no approaching PT vehicle. When a PT vehicle arrives, all other traffic in the roundabout should be controlled by traffic lights. Two methods are proposed for managing this situation: stopping the traffic in the entire roundabout by using traffic lights at all entrances to the roundabout; or closing only the PT route crossings, by using traffic lights inside the roundabout. According to Kuehn (2014), in France, most roundabouts with crossing light rail transit (LRT) routes function as normal roundabouts as long as there is no LRT, and when the LRT approaches, they become a "traffic-light junction". Through the internet search, many examples of roundabouts with direct BRT crossing routes were found in Poland, France, and the UK, showing different types of traffic lights and traffic setting details applied.

Another European study (Fontaine et al., 2015; Novales et al., 2017), surveyed traffic arrangements for LRT systems in various European cities, with an emphasis on the French experience. According to the findings, to increase the safety of LRT crossings at roundabouts, it is recommended to add traffic lights for vehicles before crossing the LRT tracks, combined with a stop line and dedicated traffic signs. From practical experience, a known problem of incompliance with the traffic lights by vehicles that did not notice the arrangement, was indicated, and it was recommended to increase the traffic lights' visibility by doubling their number (at the LRT crossing points). As a rule, a roundabout with an LRT track but without traffic lights is not recommended for implementation.

In summary, employing traffic lights to give priority to a BRT crossing the roundabout is the accepted solution in the international practice. However, the manner of using the traffic lights, their configurations, and other details of managing traffic in a roundabout vary among countries. The literature does not reflect empirical findings that could support the choice of details for such arrangements. Nor does the literature provide quantitative information regarding the effects of roundabouts with traffic lights and crossing BRT, on driver behaviours or safety.

Concerning a more general issue of traffic lights' installation at a roundabout, the professional assumptions are (MOT, 2017) that, in a multi-lane roundabout, signaling may improve traffic flow, increase junction capacity and reduce vehicle delays. In addition, traffic lights' installation is expected to reduce the accident risk associated with poor driver judgment in selecting the appropriate gap in the traffic flow when entering the roundabout. For example, Jurewicz et al. (2015) conducted a detailed survey of existing knowledge and road accident characteristics, in Australia, in order to adapt traffic settings to the *Safe System* concept. With regard to roundabouts, they concluded that traffic lights would likely reduce the risk of accidents, especially in large and multi-lane roundabouts. Furthermore, a signalized roundabout was expected to have additional safety benefits related to preventing accidents involving two-wheelers (bicycles and motorcycles), since the driver no longer needs to "search" for riders to give them the right-of-way before entering the roundabout.

Regarding the safety impact of traffic lights' installation in roundabouts, the research findings are scarce (Jurewicz et al., 2015). For example, the summary estimates on safety impacts of roundabout settings do not include values on signalized roundabouts (Elvik et al., 2009; Soteropoulos & Stadlbauer, 2017).

In a study conducted in the UK by the County Surveyors Society (1997), a positive safety contribution from installing traffic lights in roundabouts was reported: an 11% decrease in accidents and a 44% decrease in accident severity, in roundabouts with traffic lights operating 24 hours a day. In contrast, operating the traffic lights during selected hours only did not result in a safety improvement. Richards and Cuerden (2009) expanded the previous study by examining additional traffic roundabouts in the UK and found a growing preference, in practice, for operating roundabouts with traffic lights 24 hours a day. This preference is related, among other things, to better management of pedestrian traffic in a signalized roundabout, and reducing the need for a combination of two different approaches to traffic management in the same arrangement, e.g., traffic lights and giving right-of-way.

In summary, previous literature indicated that a signalized roundabout combines the geometric benefits of a regular roundabout, which are reflected in the low entry speeds and small collision angles between the vehicles within the roundabout, and the additional potential for reducing drivers' errors at the roundabout entrances. Hence, there is an expectation that the safety level of large and multi-lane roundabouts may improve as the result of traffic lights' installation.

2. METHODOLOGY

2.1 The study framework

This study aimed to explore the safety level of a signalized roundabout with crossing BRT based on observations of driver behaviours. For that purpose, the study focused on safety-related behaviours, such as red-light violations by vehicles, vehicle interactions in the roundabout entrance areas, and giving right-of-way to pedestrians by vehicles.

The signalized roundabout with a BRT route was established as a new arrangement, which incorporated changes at the intersection and in traffic settings in the nearby streets. In the "before" period, there was no BRT route on the street. As a result, a "before-after" comparison of driver behaviours was not possible. Thus, the study sought to characterize the safety level of the setting by estimating the rates of risky behaviours observed under the new arrangement and comparing them with similar indicators reported in the literature, for multi-lane roundabouts and/or signalized intersections. For example, international findings showed (Retting et al., 2003), that red-light running at a signalized intersection occurs at a frequency of 0.5%–3% of the total vehicles entering the intersection or, according to other estimates, at a frequency of between one to four vehicles per thousand vehicles passing through the intersection. Such estimates could serve as a basis for judging the study's findings.

The pilot roundabout was built at the intersection between Bialik street and HaTa'ala street in the town of Kiryat Ata, Israel. The design and construction processes were led by the Yefe Nof Company (a municipal corporation). The pilot setting was a four-legged two-lane roundabout for general vehicle traffic, with a central bi-directional BRT route crossing the roundabout (see Figure 1); the BRT route is marked by red colors. Next to one (east) side of the roundabout, BRT stops are situated, in both travel directions. Pedestrian crosswalks are arranged at three entrances of the roundabout where pedestrians may cross. Traffic lights were installed in two areas inside the roundabout, to ensure passing priority to the BRT movement. The equipment included: two standard three-color traffic lights for circular vehicle traffic, with a stop line, near each BRT crossing area; traffic lights for the BRT traffic (a tram-signal style), in both travel directions, and standard traffic lights for pedestrians which cross the BRT route near the BRT stops. All traffic lights were synchronized and activated by approaching BRT vehicles.

The roundabout construction works were completed in 2018. BRT traffic through the roundabout, with the aid of traffic lights, began in February 2019. For traffic surveillance purposes, video-cameras were installed at the site by the traffic control center. The cameras' operation began simultaneously with the BRT running through the roundabout. The cameras' observation angles could be adjusted to record the traffic-lights' or the entrance areas of the site, for the study needs. The pilot was supervised by a steering committee which included representatives of the Ministry of Transport, the Yefe Nof Company, the roundabout designers and road safety experts.

2.2 Data collection and preparation

The video-records for the study purposes - the examination of road user behaviours, were collected by the traffic control center, starting from the third week of the BRT operation. The camera records were taken at four areas of the roundabout (Figure 2): two near the traffic lights in the roundabout - zones W2, E4, and two in the entrance areas - zones W1, E3. (The zone names corresponded to the camera names in the traffic control center). It should be noted that the inside and entrance roundabout zones were not identical, due to the presence of the BRT stops near W2 zone (vs. no stops near E4 zone) and a larger number of the roundabout lanes in E3 zone (two lanes for a right turn leaving the roundabout and one lane for circular traffic, vs. two lanes in total, in W1 zone). For the study purposes, the control center cameras were directed respectively: in zones W1 and E3 - towards the roundabout entrance areas; in zones W2 and E4 - towards the traffic lights' areas and the BRT crossing route (Figure 3).

In each area, 30 hours of video-records were collected during weekdays, between hours 8-18, including rush and non-rush hours in general traffic, and hours with different frequencies of the BRT crossings. Using the video-records, vehicle samples were extracted to characterize driver behaviours under various traffic and traffic lights' conditions, in the roundabout. During the preliminary discussions with the steering committee, it was suggested that, during the pilot, it was important to carry out examinations of vehicle behaviours in the following conditions:

- In the traffic lights' areas (zones W2 and E4, in Figure 2), when the BRT passes through the roundabout, in order to estimate the level of drivers' compliance with a red light and the risk of red-light running.
- In the traffic lights' areas, at time periods without the presence of a BRT, in order to characterize the frequency of unusual driver behaviours in response to the new arrangement, such as unnecessary stopping or slowing down during a green or yellow light.
- In the entrance areas of the roundabout (zones W1 and E3, in Figure 2), under conditions with and without the BRT presence in the roundabout, in order to characterize interactions between different road users, e.g. between an incoming vehicle and vehicles traveling in the roundabout or between an incoming vehicle and a crossing pedestrian, including giving right-of-way and conflict occurrence. A conflict was identified by braking and/or change in the direction of vehicle travel (or pedestrian movement) to prevent a collision, in line with previous research (e.g. Ewing and Dumbaugh, 2009; Gitelman et al., 2017).

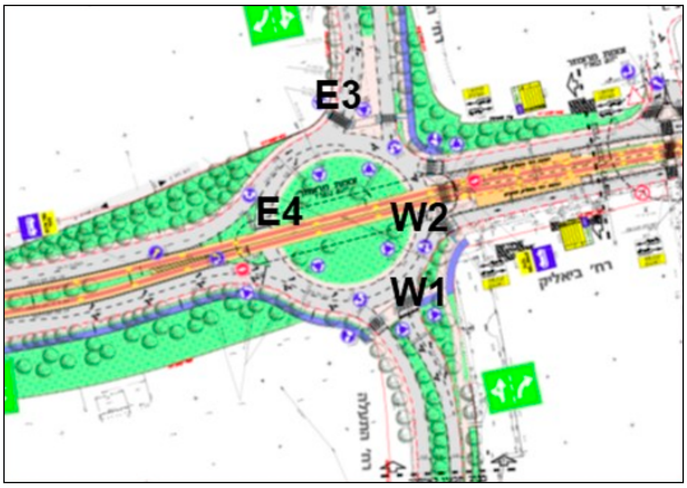


Figure 2. The four areas of video-recording in the roundabout.

Based on the video-footage, vehicle behaviours were documented manually using the pre-defined forms and rules; the forms for data coding in the study were developed using google forms. First, all the times when the traffic lights changed to red (the BRT crossed the roundabout), were documented. Subsequently, using the BRT crossing times, vehicles were sampled from the films to reflect behaviours in five situations:

Case 1 – vehicles that approached the traffic lights in the short time period before and after the appearance of a red signal;

Case 2 – vehicles that passed through the traffic lights' area during a green signal;

Case 3 – vehicles that entered the roundabout when the traffic lights were red;

Case 4 – vehicles that entered the roundabout when the traffic lights were green and other vehicles were present in the roundabout;

Case 5 – vehicles that entered the roundabout when the traffic lights were green and no other vehicles were present in the roundabout.

The *Case 1* sample was obtained from the W2/E4 camera records, at each second change of the traffic lights, where during the 10 second intervals before and after the red light appearance, behaviours of all vehicles reaching the traffic lights' area were documented. Using this sample, whether vehicles stopped at the red, as required, was examined, and estimates of noncompliance to a red light were obtained.

The *Case 2* sample was obtained from the W2/E4 camera records, at each second change of the traffic lights, by documenting the behaviour of the first vehicle reaching the traffic lights, provided it had not been standing at the red light. Using this sample, it was examined whether vehicles arriving during a green light, slowed down or stopped, when the driver did not see the behaviour of a preceding vehicle. In addition, unusual behaviours of vehicles in the traffic lights' area were examined based on the *Case 1* sample, when slowing down or stopping of the vehicles arriving at a green or yellow light, was considered.

The samples for other cases were produced using the W1/E3 cameras, by applying the following rules:

Case 3 - at each third change of the traffic lights to red, the behaviour of the first vehicle that reached the roundabout

Figure 3. Pictures from the video-recording zones, in the study.

entrance (the crosswalk marks) was documented. Using this sample, it was examined whether vehicles slowed down before entering the roundabout and gave right-of-way to other vehicles in the roundabout and to pedestrians, when a BRT was passing through the roundabout;

Case 4 - at each third change of the traffic lights to green, the behaviour of the first vehicle that reached the roundabout entrance was coded, if there were vehicles traveling in the roundabout or a pedestrian crossing at the crosswalk. With this sample, it was examined whether vehicles slowed down before entering the roundabout and gave the right-of-way to other road users, when no BRT was passing through the roundabout;

Case 5 - at every quarter of an hour, at a green light, the behaviour of the first vehicle that reached the roundabout was documented, where no other vehicle was in the roundabout. This sample enabled to estimate whether vehicles slowed down before entering the roundabout without other vehicles' presence in the roundabout. (This case was applicable for all observation hours of the study site due to the prevalence of flowing traffic conditions, see Sec. 3.1).

To estimate the sample size required for examination of each behaviour, common rules accounting for accuracy and confidence level of the indicator, were applied, as described in Hakkert and Gitelman (2007). Preliminary evaluations showed that samples of 150-300 vehicles would be sufficient for estimating various behaviour indicators. Thus, the sampling rules (as described above) were suggested to attain the samples required for estimation of each tested behaviour, while applying a uniform selection of the sample units over all the hours filmed. It can be noted that the sampling rules in the study put a greater emphasis on the cases with interactions of the road users.

To characterize the traffic conditions in the roundabout when a vehicle arrived, four categories were used: flowing, slow, standing, or "no vehicles" (in the roundabout). The traffic conditions were defined as follows: *flowing* – when the vehicles in the circular traffic passed through the roundabout (the way that was seen in the film) in less than five seconds; *slow* – when the vehicles passed in five seconds or more; "standing" – when vehicles inside the roundabout were standing. It should be noted that the literature does not suggest a common definition of flowing traffic conditions in a roundabout. The design guidelines (e.g. MOT, 2005) instruct to estimate the capacity of entry lanes, based on the circulating traffic, roundabout diameter, number of lanes and gap acceptance parameters; the design aspires to a balance between entering and circulating traffic and minimum delays, but "flowing traffic" in the roundabout is not defined. Behaviour studies of multi-lane roundabouts (e.g. Kashinsky and Balasha, 2012; Parikh and Hourdos, 2017) examined passing vehicle maneuvers but did not distinguish between various traffic conditions. Accounting for the current study site characteristics, "less than five seconds" travel (in the filmed distance) corresponds to passing speeds of 30-40 km/h and over, that satisfies the target speeds of multi-lane roundabouts (MOT, 2005) and thus, can be considered as flowing traffic conditions.

If, based on the W2/E4 camera records, a red-light running was identified, a detailed re-examination of each case was conducted, in order to: record the time of the violation - in which second after the red-light appearance the vehicle crossed the BRT route; examine what happened in the event; whether there was a slowdown or stop by the BRT and whether there was a conflict between the violating vehicle and the BRT (or another vehicle).

Based on the W1/E3 cameras, when the vehicle did not slow down before entering the roundabout and traffic was present in the roundabout, a risky situation was possible. Therefore, a re-examination was conducted of the interactions between the incoming vehicle and the vehicles that were traveling within the roundabout in order to identify conflicts in which the collision was avoided as a result of braking or changing the direction of travel by one of the vehicles involved.

2.3 Data analyses

Descriptive data analyses were conducted to produce summary values of the behaviour indicators, with confidence levels. Behaviour indicators were estimated as a percentage of a certain feature out of the sample collected, at each study area. Vehicle behaviours under various traffic conditions were compared, when applicable, using a z-test for proportions or a chi-square test for the whole distribution between categories (the difference was significant with $p<0.05$). Furthermore, to interpret the results, the values observed in the study were compared with behaviour indicators reported in the literature.

3. RESULTS AND DISCUSSION

3.1 Traffic characteristics in the roundabout

Table 1 shows a summary of the frequency of BRT passing through the roundabout and statistics of the red lights' durations, in each area of the roundabout. During the day, the mean number of traffic light closures were between 12–15 per hour, indicating that, on average, the BRT passed every four to five minutes. The duration of the red light for vehicles was about 14 (± 3) seconds in zone W2 (near the BRT stops) and about 13 (± 3) seconds in the opposite zone (E4).

Zone	Date of video-recording	Total # of red light appearances, in 10 hours	Average # of red light appearances, per hour	Red lights' duration, seconds			
				mean	sd	min	max
W1-W2	17.2.19	124	12.4	13.9	2.9	12	30
	18.2.19	120	12.0	14.1	3.2	10	29
	6.3.19	149	14.9	14.5	3.5	11	30
	total	393	13.1	14.2	3.2	10	30
E3-E4	28.3.19	143	14.3	12.5	1.6	10	27
	2.4.19*	150	15.0	13.5	3.4	11	10
	3.4.19**	143	14.3	12.7	2.5	11	27
	13.5.19	139	13.9	12.9	3.2	11	38
	total	575	14.4	12.9	2.8	10	38

Notes: *Video-recording of the entrance area only. ** Video-recording of the traffic lights' area only. In all other dates, both entrance and traffic lights' areas were recorded.

Table 1. Frequency of red lights due to BRT crossings in the roundabout, and red lights' duration statistics.

In terms of traffic conditions in the roundabout for an entering vehicle, it was found that in zone E3, nearly 100% of the entry situations were in *flowing* traffic conditions within the roundabout. In contrast, in zone W1, the traffic conditions were not uniform across various hours. In the morning, between 8-12, 90% or more cases observed were under *flowing* traffic conditions within the roundabout but there was an increase in traffic after 12 pm, so that between 13-16 the share of *flowing* traffic decreased below 80% and between 16-18 it was about 70%. On average, in this entrance area, 82% of the entering vehicles (observed) were under *flowing* traffic conditions in the roundabout, 9% under *slow* and about 9% - under "standing" traffic conditions.

In total, the study samples included behaviours of 1,240 vehicles in the traffic lights' areas, and of 1,555 vehicles in the roundabout entry areas. Most of the vehicles observed were passenger (or small commercial) cars: between 91%–97% in the W1-W2 zones, and between 89%–94% in the E3-E4 zones. The share of trucks, in various study samples, was between 2% and 8%; the share of motorcycles - between 1% and 3%.

The presence of pedestrians at the crosswalks in the roundabout was very low, between 0% and 1% of the samples collected. In total, out of about thousand cases of vehicles sampled in the traffic lights' zone (W2), only nine pedestrians were observed on the nearby signalized pedestrian crosswalk; in over 1,500 cases of vehicles sampled at the roundabout entrance areas (W1, E3), only eight pedestrians were observed on the marked crosswalks. In general, the roundabout is located at the city's outskirts and is not characterized by intensive pedestrian traffic. Similarly, bicycle traffic in the roundabout was not substantial; a limited number of (mostly, electric) bicycles were observed traveling in the roundabout.

3.2 Drivers' compliance with a red-light

Table 2 provides a summary of vehicle behaviours under the red-lights. The findings show that at the traffic lights' area in zone W2 – near the BRT stops, the vehicle traffic was tangible and that among the vehicles that reached the area under the red signal, 14% (±2.5%) did not comply with the red-light. Across various days, the share of drivers who did not stop at red was in the range of 6%–20%. In another traffic lights' area in the roundabout (E4), the vehicle traffic was smaller and all vehicles that arrived under the red signal stopped before the traffic lights; thus, in this area, no noncompliance with a red light was observed.

Using the average estimate – 14% of noncompliance with the red signal, and given the frequency of the BRT crossings in the roundabout (see Table 1), one-two red-light violations, per hour, can be expected. This rate is not low, but is not exceptional compared to drivers' behaviour at signalized intersections. For example, a summary of international findings on red-light running at signalized intersections - Retting et al. (2003), indicated that the rate of such events per a traffic-lights' cycle was in the range of 0.28–0.34, meaning that a vehicle ran at red in one out of three cycles. In another recent study conducted in the USA - Dias and Dissanayake (2014), the reported rate of red-light violations was lower, with an average of one-two cases per hour.

An examination of the cases of noncompliance with a red-light in W2 zone showed that most of the events (86%) occurred within one-two seconds of the red-light appearance, while four events only were observed in the third second or later (Figure 4-a). It can be noted, in this context, that while considering red-light running events at signalized intersections, a distinction is usually applied between the events that occurred during the first seconds of the red-light versus the longer period, of three seconds or more, whereas safety risk is mainly attributed to the events in the period greater than three seconds after the red-light appearance (Lum and Wang, 2003; Fitzsimmons et al., 2015; Lindheimer et al., 2016). Similarly, a red-light offense is recorded by the police (in Israel) starting at the third second of the red-light appearance.

Zone	Date of video-recording	Sample of vehicles that arrived at red	Rate of noncompliance to red-light: mean (sd)
W2	17.2.19	52	5.8% (3.2%)
	18.2.19	64	20.3% (5.0%)
	6.3.19	78	15.4% (4.1%)
	total	194	14.4% (2.5%)
E4	28.3.19	14	0
	3.4.19	13	0
	13.5.19	11	0
	total	38	0

Table 2. Noncompliance to red-lights in the roundabout.

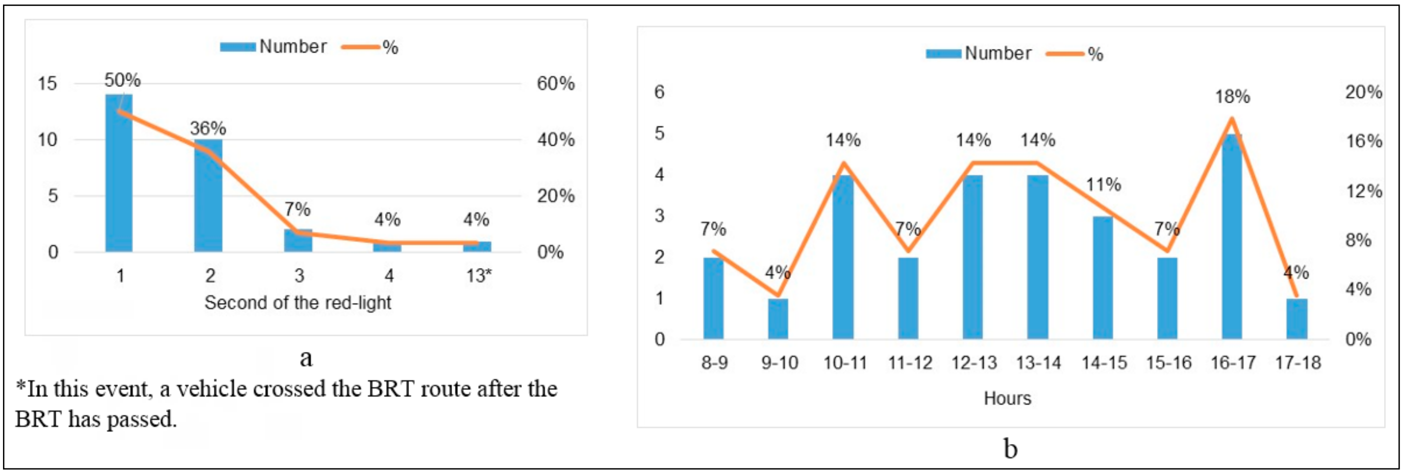


Figure 4. Distribution of red-light running events, in zone W2: (a) by seconds of the red-light appearance; (b) by hours of day.

The distribution of the red-light violations by hours indicated (Figure 4-b) that no hour was prominent in terms of the prevalence of such events: statistical tests showed that none of the hours with a seemingly higher number of violations, e.g. between 10-11, 12-13, 13-14, 16-17, was associated with a higher rate of such events (at 0.05 significance level).

Furthermore, a detailed examination of the red-light running events was conducted and found that of the 28 cases observed, risk of collision was in one case only (3.6%). In this event, one vehicle passed at the red-light and stopped on the BRT route; a collision almost occurred with another vehicle that followed, but the first vehicle continued moving and cleared the BRT route before the arrival of the BRT. Figure 5 illustrates this conflict.

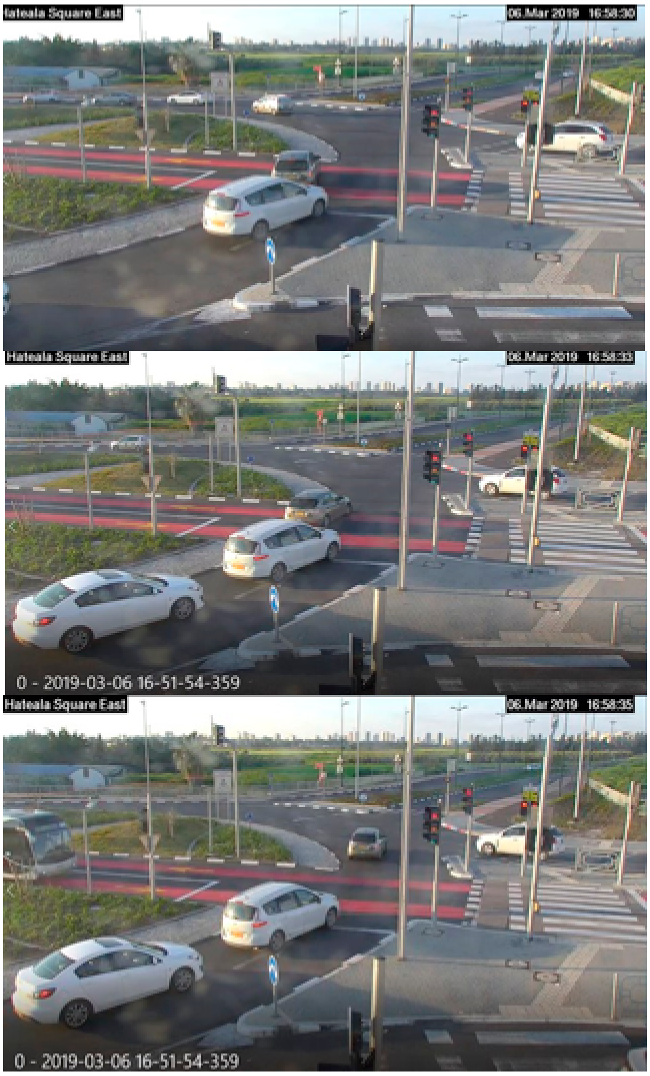


Figure 5. An example of conflict at the study site, due to incompliance with a red-light.

Among all the events, the BRT (bus) slowed down or stopped, while approaching the common zone, in three cases (10.7%); in no case there was a "near collision" situation between the vehicle and the BRT, i.e. the vehicle cleared the BRT route sufficient time before the BRT arrival. It should be noted that such consequences of originally risky situations, at the study roundabout, can be site-specific. The traffic lights at the site, to impart a passing priority to the BRT, are activated by approaching BRT units (buses), which frequently need to slow down or even stop before entering the roundabout. As a result, the BRT speeds while crossing the roundabout are not high. In addition, the BRT route includes a certain distance within the roundabout island to be passed before crossing the "vehicle zone" (see Figure 1). Both reduced speeds of the BRT and sufficient sight distances may contribute to calming possible negative outcomes of vehicle violations of the red-lights.

3.3 Unusual vehicle behaviours near the traffic lights

Table 3 shows a summary of unusual vehicle behaviours in the traffic lights' areas, such as slowing down at a green light or stopping for a yellow light. The findings suggest that in zone W2, such behaviours were rare: on average, slightly over 1% of the vehicles slowed down at a green light and about 2% stopped at a yellow light.

In contrast, in zone E4, more vehicles slowed down at a green light - about 8%, on average, and 27% stopped at a yellow light (mostly, significant differences in comparison with zone W2). In this area, there was relatively low vehicle traffic near the traffic lights. Along with the full compliance with the red light, apparently, the phenomenon of "excessive caution" was observed in this area since vehicles passing at green and yellow lights tended to slow down or stop more than usual.

Zone, Case	Traffic light	Sample of vehicles observed	Slowed down	Stopped
W2, Case 1	green	468	1.3%	0
	yellow	114	0	1.8%
W2, Case 2	green	201	1.5%	0
W2, total	green	669	1.4%	--
E4, Case 1	green	48	10.4%*	0
	yellow	11	0	27.3%#
E4, Case 2	green	166	6.6%*	0.6%
E4, total	green	214	7.5%**	--

Notes: *p<0.05, **p<0.01, #p<0.06 in comparison with W2 zone

Table 3. Unusual vehicle behaviours in traffic lights' areas of the roundabout.

3.4 Vehicle behaviours at roundabout entrances

At roundabout entrances, we examined whether vehicles that reach the roundabout were prepared to give the right-of-way to vehicles moving within the roundabout. For that, whether the vehicles slowed down (or stopped) before entering the roundabout, was checked, under various traffic conditions. If the vehicle entering the roundabout did not slow down, and there was traffic in the roundabout, the interactions between the incoming vehicle and other vehicles already present in the roundabout were considered, to recognize conflicts. The results showed that (Table 4):

- When there was no traffic inside the roundabout, in zone W1, most entering vehicles (90%–94%) did not slow down, with no difference in this behaviour if there was a green or red light in the roundabout (p=0.35). Similarly, in zone E3, most entering vehicles (87%–89%) did not slow down, and this behaviour was similar among vehicles that entered during a green or red light (p=0.37). This implies that the entering vehicles' behaviour was actually unaffected by the traffic signal. The rates of not slowing down when entering the roundabout under no traffic conditions, can be treated as a "basic" value of such behaviour to compare with other traffic conditions.
- In the presence of traffic in the roundabout, the rates of not slowing down by entering vehicles were substantially lower than under "no vehicles" conditions. Nonetheless, this warning phenomenon was observed at both entrance areas: in 3%–16% of the samples in zone W1 and 12%–23%

in zone E3. In both areas, the rates of "no speed change" during the entrance were consistently higher under the red vs. green lights in the roundabout (see *Case 3* vs. *Case 4* findings, in Table 4), with a significant difference is some comparisons.

In such situations – when traffic is present in the roundabout but an entering vehicle did not slow down, there is a potential for a collision between the incoming vehicle and the vehicles travelling in the roundabout. All such events were re-examined in the study data to identify conflicts - events with braking or change in the travel direction by one of the parties involved in the interaction. The detailed consideration comprised: in zone E3 - 22 cases of "no speed change" under *flowing* conditions in *Case 3* and 47 - in *Case 4*; in zone W1 – 6 cases of "no speed change" under *flowing* and 5 cases under "standing" conditions in *Case 3*, and 18 events – under *flowing* conditions in *Case 4* (see samples in Table 4). It revealed that, in most cases, when a particular vehicle entered the roundabout, there was no vehicle traveling in the nearby lane or that the vehicle driving in the roundabout was sufficiently distant so that the incoming vehicle did not interfere with its movement.

More specifically, in zone E3, there are two entry lanes into the roundabout, while within the roundabout there are three travel lanes, two for exiting the roundabout (towards Haifa) and one that turns left through the traffic lights (see Figures 1-2). Most of the traffic in this part of the roundabout goes towards Haifa, including the vehicles entering the roundabout (which actually used the roundabout for making a right turn). Consequently, in the existing arrangement, there is a reduced risk of conflicts between the vehicles due to rare lane-crossing movements within the roundabout by the entering vehicles.

Regarding zone W1, the analysis of the cases of entry into the roundabout without slowing down found that (see samples in Table 4-a):

- Among the cases when the traffic light was red and *flowing* traffic inside the roundabout (see *Case 3*), mostly, there was no vehicle in the right lane of the roundabout and therefore, the entrance of the vehicle (which did not slow down) did not create a disturbance to traffic in the roundabout. But in one case (out of six), there was a vehicle in the right lane and, thus, the vehicle that entered caused the vehicle inside the roundabout to brake, creating a conflict.
- In all the cases of entrance when the traffic light was red and "standing" traffic in the roundabout (*Case 3*), the vehicle that entered joined the end of the standing queue of vehicles before the traffic lights, and there was no moving vehicle in the right lane of the roundabout, so that no conflict occurred.
- In the sample of entrance at a green light and with *flowing* traffic conditions (*Case 4*), no conflicts were observed because the right lane inside the roundabout was clear and/or the incoming vehicle turned right (out of the roundabout) before the vehicle that was in the roundabout traffic arrived to the same point, so that the incoming vehicle did not interfere with the traffic in the roundabout.

a – Zone W1

Case	Traffic conditions in the roundabout	Sample of vehicles observed	Slowed down	Stopped	No speed change (# of cases)	p-value
Case 3	flowing	75	33.3%	58.7%	8.0% (6)	0.155*
	slow	12	50.0%	50.0%	0.0%	--
	standing	31	16.1%	67.7%	16.1% (5)	0.015*
	no vehicles	20	10.0%	0.0%	90.0%	0.608#
	total	138	27.5%	51.4%	21.0%	0.000*
Case 4	flowing	525	33.5%	63.0%	3.4% (18)	
	slow	54	25.9%	74.1%	0%	
	standing	30	10.0%	90.0%	0%	
	no vehicles	1	0	100%	0%	
	total	610	31.6%	65.4%	3.0%	
Case 5	no vehicles	141	5.7%	0.7%	93.6%	

b – Zone E3

Case	Traffic conditions in the roundabout	Sample of vehicles observed	Slowed down	Stopped	No speed change (# of cases)	p-value
Case 3	flowing	94	47.9%	28.7%	23.4% (22)	0.016*
	slow	1	0	0	100%	--
	standing	0	--	--	--	--
	no vehicles	61	8.2%	3.3%	88.5%	0.712#
	total	156	32.1%	18.6%	49.4%	0.000*
Case 4	flowing	389	57.8%	30.1%	12.1% (47)	
	slow	1	0	100%	0	
	standing	0	--	--	--	
	no vehicles	1	0	100%	0	
	total	391	57.5%	30.4%	12.0%	
Case 5	no vehicles	119	13.4%	0%	86.6%	

Notes: * in comparison of *Case 3* and *Case 4*; # in comparison of *Case 3* and *Case 5*.

Table 4. Vehicle behaviours when entering the roundabout.

In total, in zone W1, vehicle conflicts were observed in 1% of the total sample of vehicles that entered the roundabout at a red-light, under *flowing* traffic conditions, whereas in the remaining situations, no conflicts were identified. Similarly, as mentioned above, no vehicle conflicts were identified in another entrance zone. Hence, the prevalence of conflicts in the study roundabout entry areas was not high but comparable to other traffic arrangements. Yet, rare conflicts in potentially dangerous situations, in this study, can be site-specific, since a substantial share of the incoming traffic, in the roundabout, used it for making a right-turn and did not need to cross the internal lanes.

In a more general sense, it should be noted that the share of vehicles observed as not slowing down when entering the study roundabout was surprisingly high as the "roundabout" setting implies that all incoming vehicles will slow down when entering the intersection. The safety benefits of roundabouts are typically related to low entry speeds and small collision angles (e.g. Jurewicz et al., 2015; Soteropoulos & Stadlbauer, 2017); it is possible that some of these benefits disappear in multi-lane roundabouts, for example, due to a wider entrance. More safety problems associated with entering multi-lane roundabouts are indeed discussed in the literature (Pecchini et al., 2014; Jurewicz et al., 2015).

As expected, the rate of not slowing vehicles was substantially lower when traffic was present in the roundabout, but still, some 10%-20% of the entering vehicles did not slow down, in the current study, and this behaviour was more frequent under the red-lights (in the roundabout). We are not aware of previous research findings on vehicle behavior indicators that could assist in judging these results. We believe that more observational research is needed to characterize typical vehicle behaviours at multi-lane roundabouts and, thereafter, to assess the impacts of various infrastructure solutions.

3.5 Giving right-of-way to pedestrians

In all cases with pedestrians present while vehicles entered the roundabout, we examined whether vehicles gave the right-of-way to crossing pedestrians (Table 5). It was observed that in less than 1% of the cases of vehicles entering the roundabout, there were also pedestrians present at the crosswalks. In many interactions observed - about 38%, on average, the driver did not give right-of-way to a pedestrian crossing at the entrance to the roundabout. This finding is not surprising, because not-yielding to a pedestrian, at a marked crosswalk, is a well-known phenomenon, especially at multi-lane crosswalks.

For example, an observational study at urban intersections in Israel (Gitelman et al., 2019), found that at non-signalized crosswalks, drivers did not yield to pedestrians: in 20%–30% of cases in the nearby lane, and in half the cases in the far lane (related to the crossing pedestrian). In addition, international literature indicates that the driver's disregard for the presence of pedestrians increases in multi-lane roundabouts due to the higher complexity of the driving task at the entrance to the roundabout, the multiplicity of possible conflict points with internal vehicle traffic, etc. (Salamati et al., 2013; Jurewicz et al., 2015).

The difference in disregarding pedestrian presence by the entering vehicles as dependent on the traffic lights' condition in the roundabout (i.e. entering under a red vs. a green light, by comparing *Case 3* and *Case 4*, in Table 5) cannot be estimated in this study, due to the small amount of vehicle-pedestrian interactions observed.

4. CONCLUSIONS

In light of the unfamiliarity of Israeli drivers with signalized roundabouts with a crossing BRT, and limited empirical findings in the literature, an observational study of safety-

Zone, Case	Traffic conditions in the roundabout	Sample of vehicles observed	Pedestrian was present	Vehicle did not give right-of-way to pedestrian	Rate of pedestrian presence while vehicle enters the roundabout	Rate of not giving right-of-way to pedestrian
W1, Case 3	flowing	75	0	--	0	--
	slow	12	0	--	0	--
	standing	31	0	--	0	--
	no vehicles	20	1	1	5.0%	100%
	total	138	1	1	0.7%	100%
W1, Case 4	flowing	525	3	1	0.6%	33%
	slow	54	0	--	0	--
	standing	30	0	--	0	--
	no vehicles	1	1	0	--	0%
	total	610	4	1	0.7%	25%
E3, Case 3	flowing	94	0	--	0	--
	slow	1	0	--	--	--
	standing	0	--	--	--	--
	no vehicles	61	0	--	0	--
	total	156	0	--	0	--
E3, Case 4	flowing	389	2	1	0.5%	50%
	slow	1	0	--	--	--
	standing	0	0	--	--	--
	no vehicles	1	1	0	--	0%
	total	391	3	1	0.8%	33%
W1 + E3, all Cases	all	1295	8	3	0.6%	37.5%

Table 5. Vehicle-pedestrian interactions while entering the roundabout.

related behaviours was conducted at the site where such an arrangement was installed, during the initial period of its operation (a pilot). The study results showed that, in total, the safety level of the roundabout was comparable to other settings, yet risky driver behaviours were present both near the traffic lights and in the entrance areas.

The prevalence of the red-light running in the study roundabout was similar to that reported in the literature for signalized intersections. In general, the compliance of drivers with a red-light inside the study roundabout was not much different compared to that at a regular intersection. In addition, signs of "excessive caution" were observed in driver behaviours near a green and yellow traffic light inside the roundabout, that may contribute to improving the safety level of this arrangement. Nonetheless, in light of the events of vehicles' violations of the red-light, the BRT's speed in the roundabout should not be increased in the future, in order to reduce the risk of collisions, even in the case of vehicle incompliance with a red-light.

The study did not support the concerns about the development of risky situations due to drivers' confusion by the new arrangement. The drivers did not exhibit substantial problems in understanding the traffic light signals inside the roundabout. Regarding driver behaviours when enter the roundabout, in some conditions those were found unaffected by the traffic lights' signal, while in others, a higher tendency to not slowing down when entering the roundabout was indicated under the red, as compared to a green traffic light, which was somewhat counterintuitive. The study found substantial rates of not slowing down by vehicles which enter a multi-lane roundabout, with possible safety risks, and this topic needs future research, in general. Driver's disregard of the presence of crossing pedestrians, in the study roundabout entrance areas, was high, as expected in multi-lane roundabouts.

In summary, the new arrangement was not associated with unusual safety risks. Therefore, it was decided to proceed with the operation of the signalized roundabout with a BRT priority at the site tested. However, the question of expanding the pilot experience to other sites appears to be more complex. Some findings seem to be site-specific, for example, due to the pre-defined not high speeds of the crossing BRT; substantial shares of entering vehicles which used the site for making a right-turn only (thus, preventing conflicts of "crossing" vehicle movements inside the roundabout) and low pedestrian presence. Furthermore, as was indicated by the steering committee, the pilot findings showed proper safety functioning of the arrangement at the test site, but do not provide answers about capacity and geometry issues in the design of such settings, in general. Thus, for practical needs, further research would be useful to better fit infrastructure design solutions to various levels of traffic volumes at signalized roundabouts with crossing BRT.

The current study limitations lie in its scope – one site examined, during its pilot operation. More extensive observational research is needed to characterize typical vehicle behaviours at multi-lane roundabouts, in general, and, more specifically, at signalized roundabouts with crossing BRT/LRT; future research should have a particular focus on road user interactions and conflict analysis. Before-after observational and accident studies would be useful, in this context, to assess the impacts of various infrastructure solutions, while considering both the traffic and road environment conditions of the sites examined.

Acknowledgements

This study was commissioned by the Yefe Nof Company, Israel. The authors would like to thank Eng. Sharona Cohen from the Traffic Control Center, for collecting video-records for this study, and Mss. Irina Grabarnick for the preparation of the study data. The study team is grateful to the steering committee of the pilot for multiple fruitful discussions on the study framework and its findings.

REFERENCES

Brilon, W. (2011). *Roundabouts: A State of the art in Germany*. http://teachamerica.com/RAB14/RAB14papers/RAB14ppr045_Brilon.pdf

County Surveyors' Society (1997). *A review of signal-controlled roundabouts*. CSS, Gloucester, UK.

Dias, I., Dissanayake, S. (2014). Characteristics of red-light-running crashes and evaluation of retro-reflective signal backplates in preventing red-light-running violations. *Advances in Transportation Studies, 34*, 19-32.

Duduta, N., Adriazola, C., Hidalgo, D., Lindau, L. A., Jaffe, R. (2015). Traffic safety in surface public transport systems: a synthesis of research. *Public Transport, 7(2)*, 121-137. https://doi.org/10.1007/s12469-014-0087-y

Elvik, R., Hoye, A., Vaa, T. and Sorensen, M. (2009). *The Handbook of Road Safety Measures*. 2nd Edition. Emerald.

Ewing, R., and Dumbaugh, E. (2009). The built environment and traffic safety: A review of empirical evidence. *Journal of Planning Literature, 23(4)*, 347-367.

Finn, B., Heddebaut, O., Kerkhof, A., Rambaud, F., Sbert Lozano, O., Soulas, C. (2011). *Buses with high level of service: Fundamental characteristics and recommendations for decision-making and research*. Results from 35 European cities. Final report – COST action TU0603.

Fitzsimmons, E. J., Schrock, S. D., Lindheimer, T. E. (2015). *Evaluation of Intersection Confirmation Lights in Medium to Large Communities in Iowa to Reduce Red Light Running Violations*. University of Kansas, Lawrence, USA.

Fontaine, L., Betrand, D., Gaivoto C. et al. (2015). *Operation and safety of tramways in interaction with public space. Analysis and outcomes*. Detailed report. COST TU1103 Action Final report.

Gitelman, V., Pesahov, F., Carmel, R., Chen, S. (2017). Exploring the characteristics of potential and current users of mobility scooters, among older people in Israel. *Transportation Research Part F, 46*, 373-389.

Gitelman, V., Carmel, R., Korchatov, A. (2018). Assessing Safety Implications of Bus Priority Systems: A Case-Study of a New BRT System in the Haifa Metropolitan Area. Chapter 3 in: *Advances in Transport Policy and Planning. Preparing for the New Era of Transport Policies: Learning from Experience*, Vol. 1, 63-91.

Gitelman, V., Levi, S., Carmel, R., Korchatov, A., Hakkert, S. (2019). Exploring patterns of child pedestrian behaviors at urban intersections. *Accident Analysis and Prevention, 122*, 36-47.

Gitelman, V., Korchatov, A., Elias, W. (2020). An Examination of the Safety Impacts of Bus Priority Routes in Major Israeli Cities. *Sustainability 2020, 12*, 8617; doi:10.3390/su12208617

Hakkert, A.S., Gitelman, V. (eds.) (2007). *Road Safety Performance Indicators: Manual*. Deliverable D3.8 of the EU FP6 project SafetyNet.

Hidalgo, D., Pereira, L., Estupinan, N., Jimenez, P.L. (2013). TransMilenio BRT system in Bogota, high performance and positive impact - Main results of an ex-post evaluation. *Research in Transportation Economics, 39*, 133-138. doi:10.1016/j.retrec.2012.06.005

Ingvardson, J. B., & Nielsen, O. A. (2018). Effects of new bus and rail rapid transit systems – an international review. *Transport Reviews, 38(1)*, 96-116.

ITDP (2017). *The (New) BRT Planning Guide. Institute for Transportation and Development Policy*. New York, NY, USA. https://brtguide.itdp.org/branch/master/guide/intersections-and-signal-control/brt-lanes-at-roundabouts#exclusive-lane-along-the-inside-of-a-roundabout

Jurewicz, C., Tofler, S., Makwasha, T. (2015). *Improving the performance of Safe System infrastructure*. Research report AP-R498-15, Austroads, Sidney, Australia.
Kashinsky, D. and Balasha, D. (2012). *Study of safety in roundabouts in dual carriageways*. Research report S/40/2012, Transportation Research Institute, Technion, Haifa, Israel.
Kuehn, A. (2014). *Technical design parameters and planning philosophy for Aarhus Letbane*. http://www.letbanen.dk/media/146080/technical-parameters-planning-philosophy-aarhus-final-ve_.pdf
Lindheimer, T. E., Fitzsimmons, E.J., Schrock, S.D. (2016). Evaluation of confirmation lights on red light running violations by time-into-red phase. *Transportation Research Record, 2584*, 24-29.
Lum, K.M. and Wong, Y.D. (2003). A before-and-after study of driver stopping propensity at red light camera intersections. *Accident Analysis & Prevention, 35*, 111-120.
MOT (2005). *Roundabout design guidelines*. Ministry of Transport, Jerusalem, Israel.
MOT (2012). *Public transport development: strategic program*. Ministry of Transport, Jerusalem, Israel.
MOT (2017). *Guidelines for planning and design of traffic lights* (draft version). Ministry of Transport, Jerusalem, Israel.
Novales, M., Marti, C.M., Teixeira, M., Schmitt, D., Morley, R., Fontaine, L. (2017). Use and design of safe roundabouts in Light Rail Transit (LRT) networks. In: *Transportation Research Board 96th Annual Meeting Compendium of Papers*, Washington DC.
Paganelli, F. (2020). Urban Mobility and Transportation. In: Filho, W.L., Azul, A.M., Brandli, L. et al., *Sustainable cities and communities*. *Encyclopedia of the UN Sustainable Development Goals*, 887-899. Springer International Publishing, Cham, Switzerland.
Parikh, G. and Hourdos, J. (2017). *Evaluation of safety and mobility of two-lane roundabouts*. Report No. MN/RC 2017-30. University of Minnesota, St.Paul, Minnesota, USA.
Pecchini, D., Mauro, R., Giuliani, F. (2014). Model of potential crash rates of rural roundabouts with geometrical features. *Journal of Transportation Engineering*, *140(11)*, 1-13.
Planning Administration (2020). *Basic principles for public transportation' and sustainable traffic' biased planning - criteria for submitting plans to planning institutions*. Planning Administration, Jerusalem, Israel. https://www.gov.il/he/departments/general/planning_public_transp_sustainable_mov
Retting, R.A., Ferguson, S.A. & Hakkert, A.S. (2003). Effects of red light cameras on violations and crashes: a review of the international literature. *Traffic Injury Prevention, 4(1),* 17-23, doi: 10.1080/15389580309858
Richards, D. and Cuerden, R. (2009). *The relationship between speed and car driver injury severity*. Road safety Web publication 9, Department of Transport, London, UK.
Rupprecht Consult (2019). *Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan*, 2nd ed.; Forschung, B.G., ed.; Rupprecht Consult, Cologne, Germany.
Salamati, K., Schroeder, B., Geruschat, D., Rouphail, N. (2013). Event-based modeling of driver yielding behavior to pedestrians at two-lane roundabout approaches. *Transportation Research Record, 2389*, 1-11.
Soteropoulos, A., Stadlbauer, S. (2017). *Convert junction to roundabout*. European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu.
TCRP (2007). *Bus rapid transit practitioner's guide*. TCRP report 118, Transit Cooperative Research Program (TCRP), Washington, DC.
Vecino-Ortiz, A.I. and Hyder, A.A. (2015). Road safety effects of Bus Rapid Transit (BRT) systems: a call for evidence. *Journal of Urban Health, 92(5)*, 940-946. https://doi.org/10.1007/s11524-015-9975-y
Winters, M., Buehler, R., Götschi, T. (2017). Policies to promote active travel: evidence from reviews of the literature. *Built Environment and Health*, *4*, 278-285.