**Redesign of Existing Motorway Sections to Increase Capacity: A Pilot Evaluation of Safety-related Impacts in Israel**

**1.2. Literature survey**

Good quality, standard hard shoulders and road lanes are considered to play an important role in ensuring both efficient and fluid traffic flow and the safety of all road users (FHWA, 2007; RISER, 2005; Stamatiadis et al., 2009). For example, the right (outside) shoulder of a motorway has a number of significant functions: providing a stopping area for vehicles in the event of an emergency or breakdown; enabling vehicles to maneuver to prevent collision; helping drivers successfully contend with situations of momentary loss of control or correcting driving errors; serving as an area for requisite roadside maintenance; supporting the pavement structure and water drainage; and more (MOT, 2018). Numerous studies have shown that the width of the shoulder has a direct impact on the occurrence of road accidents. In fact, a correlation has been found between reducing the width of a shoulder and an increased risk of accidents (e.g., Council and Stewart, 1999; Gitelman et al., 2018; Stamatiadis et al., 2009).

However, due to steadily increasing congestion on the main road network, in recent decades the motorway has been put to additional uses, e.g., buses running on the shoulders (FHWA, 2016; Gitelman et al., 2016).

Based on the accumulated experience of developed countries, in all functional states of a motorway – the typical cross-section, the as-built cross-section, or preferential lanes – it is important to ensure that the right shoulder is at least 3m wide or more (e.g., Caltrans, 2018; CEDR, 2012; FHWA, 2016).

**1.1. The pilot: redesign of motorway sections**

A redesign of the road layout was implemented in two sections of a motorway (Road 1) connecting Israel’s two major cities, Tel-Aviv and Jerusalem. The redesign aimed to expand the current roadway from two to three travel lanes, in both travel directions, by narrowing both shoulders and the existing two traffic lanes. The redesigned sections were:

Section 1 – Between the Anava and Latrun interchanges, along an 8.6 km length of road between the 25 km and 33.6 km markers;

Section 2 – Between the Latrun and Shar HaGay interchanges, along a 4.9 km length of road between the 33.6 km and 38.5 km markers, for a total road length of 13.5 km in both travel directions.

We should point out that the motorway, both before and after the sections in question, comprises three lanes in each direction. Due to heavy traffic congestion, (annual average daily traffic [AADT] of 112,000 vehicles in 2016), a change in the lateral cross-section was carried out to increase roadway capacity. A third travel lane was added to each travel direction at the expense of reducing lane and shoulder width. For example, in Section 2 on the Jerusalem-bound carriageway, the new cross sections included: a 3.0–3.2 m wide shoulder; a 3.6 m wide right-hand lane; two additional 3.3 m wide lanes; and a 0.6 m wide left shoulder. The changes on the Tel Aviv-bound carriageway involved: a 1.2–2.2 m wide right shoulder; a 3.6 m wide right-hand lane; two additional 3.3 m wide lanes; and a 1.2 m wide left shoulder. Figure 1 displays a photo of the new section, with three travel lanes in each direction.

The dates for operation of the redesigned road cross sections were: Section 1, late January 2018; Section 2, late November 2017.

Due to the restricted layout, the speed limit on the redesigned sections was reduced to 90 kph, while on the adjacent sections the speed limits remained 110 kph and 100 kph.

**2. Follow-up evaluation: data and methods**

The redesign was introduced by the Ministry of Transport as a pilot and was followed-up by an evaluation, to examine capacity changes and safety-related impacts.

The redesigned road layout is intended to improve the traffic flow, increase travel speeds, and reduce transit times within the section, especially during rush hour traffic. Moreover, it is imperative to ensure that the new road layout does not adversely affect the level of safety in these sections.

The evaluation included after-before analysis of traffic volumes, travel speeds and road accident occurrences. In total, the evaluation included two "after" periods: 1) the first half-year of the operation and 2) two-years of the operation, which were compared with a "before" period, prior to effecting changes in the road layout.

We should point out that no orderly research with a predefined, uniform measurement framework in both the “before” and “after” periods was requested for the purpose of the evaluation, but a number of accompanying checks were carried out in short time periods for the purpose of Ministry of Transport monitoring. Despite the lack of a uniform framework, the findings of the checks conducted during the pilot monitoring period enabled us to draw conclusions regarding the effect of the redesigned road layout on traffic flow and safety.

For Section 2, before construction of the new road layout and during the initial monitoring period, video footage was filmed for a week-long period to conduct traffic counts and measure traveling speed in each lane at all hours of the day. Furthermore, from the total number of vehicles passing through this section, a sampling was carried out (based on license plate numbers), while entry and exit times to and from the section were recorded during rush hour traffic: between 7:00 am–10:00 am and 4:00 pm**–**7:00 pm. Transit times were then measured and transit speeds in the section were calculated accordingly. The “before” measurements were made in November 2017 and the “after” measurements in January 2018. In addition, for those same months, Google data was obtained from the Ministry of Transport (Jerusalem Division) database on the section transit speeds in both travel directions for various hours of the day.

For Section 1, the travel speed data was obtained from NTIC, representing the transit speeds of vehicles moving between sensors located along the route. In total, in the evaluated sections, six identification sensors were installed to enable monitoring of speeds in five sub-sections, three of which were adjacent to the interchanges and two were between the interchanges. The data was obtained for January–July 2018 and enabled us to make a comparison between the “before” period (January 2018) and the “after” period (the remaining months). We conducted evaluations of the average speed when passing through the road section for various hours of the day on weekdays. Another issue arising under the conditions of the new road layout was that of the representative speed for vehicles traveling through the redesigned sections; we needed to examine their suitability for the maximum speed limit that had been set for 90 kph. The assumption was that the average speed estimates during the non-rush-hour daytime hours reflect the representative speed – the drivers’ selection of traveling speed.

During the second monitoring period, speed data for the redesigned road section was obtained for weekdays during February and July 2020 (both before and after the first lockdown in the COVID-19 pandemic period). For each of the five sub-sections mentioned above, estimates were obtained from NTIC of the average speed during transition of the section, for various hours of the day. The issues examined were changes in travel speed compared with previous measurements and identification of the representative travel speeds in the redesigned road layout sections some two years after it had been opened. The speed estimates were used only for those hours in which the measurement was based on the identification of 30 or more vehicles. Moreover, the speed estimates were weighted over a number of days, taking into account the size of the measurement samples during the appropriate hours.

Examination of the safety level in the redesigned road sections focused on the numbers and characteristics of road traffic accidents occurring during the period in which the new road sections were in service and comparing them with similar data in the period prior to it being opened. The redesigned road layout was intended to improve the traffic flow and to enable increased traffic volumes in that specific road section, especially during rush hour periods. Therefore, we decided to look at changes in the accident rates taking into consideration the differences in exposure in the period following the redesign compared with the “before” period. The road traffic accident data was derived from the Central Bureau of Statistics (CBS) road traffic accident files. The information on traffic volumes, in each period, was derived from the CBS “traffic count” files and the measurements made during the project (for Section 2). The traffic volume estimates are weekday AADT figures.

In the first evaluation, we compared data of accidents occurring on the redesigned road sections during February to August 2018 with similar time periods in previous years, 2015–2017 (to rule out the seasonality factor).

In addition, the traffic police provided reports of safety-related events for the redesigned sections, for eight months of 2018, enabling comparison between the initial operation period of the redesigned road sections (February–August) and a before period (January).

In the second evaluation, traffic accident data from 2018–2019 was used as the "after” period, while traffic accident data from 2015–2017 was used as the “before” period. The statistical checks included: 1) examination of the average number of accidents (or incidents) during the period; a substantial difference was found when the traffic accident estimate in one period deviated from the mean by ± two standard deviations (SD) of another period; 2) examination of the changes in the rate of accidents in relation to exposure, using the t-test. Moreover, in the second evaluation, a change in traffic accidents in the redesigned road sections was examined in comparison with a control group (the total number of traffic accidents on the intercity road network), via odds ratio calculations.

**3. Results**

**3.1. First half-year of operation**

**a. Traffic volumes, travel speeds, transit times**

Table 1 presents a summary of daily traffic volumes and average travel speeds, before and after the construction of the redesigned road layout, for Section 2. Figure 2 depicts an example for comparison between the average travel speeds, at all hours of the day, during both periods; these illustrations depict a specific travel speed at one point rather than the overall transit speeds in the section. The averages show that as a result of the redesigned road layout, on the Jerusalem-bound carriageway there was a marked increase in the daily traffic volume, between 19%–28% compared with the situation beforehand, with an average 24% addition to daily traffic volume. On the Tel-Aviv-bound carriageway, a smaller increase of 4% on average was noted.

In terms of the speed levels, it emerged that on the Jerusalem-bound carriageway, if “before” there were hours with low average speeds, within the 50–90 kph range, mainly between 7:00 am–11:00 am and 3:00 pm–8:00 pm, in the newly redesigned road layout, the travel speeds were above 100 kph, at all times of the day. In other words, in this travel direction, in the new situation, the travel speeds increased to free travel speeds, at all times of the day. It is important to remember that this relates to a specific travel speed in the middle of the section.

In contrast, on the Tel-Aviv-bound carriageway, “before” there were hardly any hours with travel speeds less than 100 kph, and this state of affairs did not materially change after the redesigned road layout section was opened. However, on the right-hand lane, speeds of less than 100 kph were observed, mainly at nighttime. This might be indicative of a potential impact of the reduced-width shoulder in the redesigned road section that led to diminished speed in the right-hand lane.

Table 2 shows the transit times and transit speeds in the section, during rush hour, for Section 2, both before and after construction of the new road layout. As a result of the redesigned road layout, we can see:

* On the Jerusalem-bound carriageway, during the morning rush hour, the transit speeds in the section increased by 12–30 kph, and in parallel the transit times in the section were shortened by a range of between 20 seconds to one minute or more. Similarly, between 4:00 pm–7:00 pm, the transit speeds in the section increased by 11–24 kph, and the transit times in the section were shortened by a range of between 20 seconds to one minute or more.
* On the Tel-Aviv-bound carriageway, during the morning hours, the transit speeds in the section increased by 4–29 kph, and the transit times in the section were shortened by a range of between four to 51 seconds. Between the hours of 4:00 pm–7:00 pm the changes were more significant: the transit speeds in the section increased by 23–33 kph, and the transit times in the section were shortened by a range of between 35 seconds to two minutes.

Figure 3 depicts a comparison between the transit speeds in Section 2, during the "after” period compared with the period “before” the redesigned road layout, based on Google data. It is apparent that following the redesign of the road layout, the transit speeds in the section increased in both travel directions. On average, at all times of the day, there was an increase of 15 kph in the speed of vehicles traveling to Jerusalem, and an increase of 8 kph in the speed of vehicles traveling to Tel-Aviv. During rush hour, the transit speeds in the section on the Jerusalem-bound carriageway rose by 25–30 kph, and on the Tel-Aviv-bound carriageway, they increased by 15–40 kph. In a similar manner to the previous findings, on the Tel-Aviv-bound carriageway, the change in transit speeds in the section was mixed, with an increase in transit speeds during rush hour, especially during those hours characterized by lower speeds during the “before” period, and a slight decrease in the transit speeds at nighttime. This last finding might have been influenced by the narrow right shoulder that led to a decrease in travel speeds at night.

Table 3 portrays a summary of the average vehicle transit speeds at all times of the day in five sub-sections of the two redesigned road sections, during 2018, according to NTIC data. For Section 1, the findings show a comparison between the “before” period (January 2018) and the “after” period (commencing in February 2018); for Section 2, the findings illustrate the speed level during the period in which the redesigned road layout became operational. Figure 4 brings examples of the level of travel speeds for various hours of the day, in a number of sub-sections. We can see that as a result of the redesigned road layout, in Section 1:

* There was in increase in the travel speeds on the Jerusalem-bound carriageway during rush hour, and overall, at all times of the day, an increase in the average speed was observed: +2.6 kph in the sub-section after Anava Interchange; +7.5 kph in the sub-section between the two interchanges; +3.7 kph in the sub-section before Latrun Interchange.
* On the Tel-Aviv-bound carriageway, in the sub-section after Latrun Interchange, the travel speeds did not increase; overall, at all times of the day, a slight decrease in the average speed was observed: -2.3 kph, and this decrease was more tangible at nighttime. In the sub-section between the two interchanges, there was an increase in travel speeds during the daytime and a decrease at nighttime; the average change in the travel speeds at all times of the day together was +2.7 kph. An increase in the travel speeds during the daytime with a concomitant decrease at nighttime was also noted in the sub-section before Anava Interchange, and overall, at all times of the day, hardly any noticeable change was observed: +0.5 kph. In other words, these findings too are indicative of a mitigating effect on the travel speeds at nighttime, apparently due to the width-reduced shoulder.
* The travel speed levels were stable (over various months) and indicated the following representative travel speeds during the daytime: between 95–100 kph in the sub-sections adjacent to the interchanges, and higher in the middle of the section, above 110 kph on the Jerusalem-bound carriageway, and between 105–110 kph on the Tel-Aviv-bound carriageway.

According to Table 3, in Section 2, during the first operational period of the redesigned road layout, in the sub-section between the two interchanges, the travel speed levels, on the whole, were stable (in a comparison among the various months) and within a range of 100–105 kph. In the sub-section adjacent to Shar HaGay Interchange, the travel speed levels were also stable, around 90 kph. In Section 2 as well, the travel speeds in the vicinity of the interchange appeared to be lower, at a level of 90 kph, while the average travel speeds in the section rose to 100–105 kph.

Overall, the representative speed levels – the average speeds of the vehicles in the redesigned sections – during the daytime, were between 95–100 kph, near to the interchanges, and 105–110 kph in the sections between the interchanges. The travel speed levels at night were similar (in most cases) or lower, compared with the daytime. The as-built cross-section was operated with a permitted speed limit of 90 kph. Consequently, the actual travel speeds were higher than the permitted speed limit. The travel speeds on the redesigned road sections were similar to the travel speeds on the motorways measured in the national survey (National Road Safety Authority, 2018).

**b. Road traffic accidents**

Table 4 depicts concentrated data on daily traffic volumes in the redesigned road sections and the number of road traffic accidents recorded in the first seven months after the redesigned road layout became operational, as well as parallel periods of previous years. The findings showed that the weighted estimate of the increase in daily traffic volume, on weekdays, as a result of the new road layout becoming operational, was +20%. In terms of the changes in road traffic accidents, it emerged that the total number of accidents involving casualties in the period after the redesigned road layout became operational, was no different to the average figure of previous years, while the percentage of serious road traffic accidents was lower than in previous years. Moreover, the number of accidents with casualties in relation to exposure was lower during the period after the redesigned road layout became operational than in the preceding years (though the change was not significant). In other words, during the initial period after the redesigned road layout became operational, no decline in the level of safety was observed compared with the preceding years. However, this assessment was preliminary due to the short monitoring period.

In addition, information was obtained from the traffic police regarding safety-related incidents occurring in the redesigned road sections between January and August 2018. Table 5 presents a summary of the figures regarding these incidents. The statistical estimates of incident occurrence (monthly average) during February–August 2018 were compared with the incident occurrence in January 2018 (“before”) so as to examine the changes occurring during the period after the redesigned road layout became operational.

The findings showed that the total number of incidents and the statistics of the majority of the types of incidents were no different during the period after the redesigned road layout became operational compared with the period beforehand, apart from two specific types of incidents: “hazard/infrastructure fault/obstacle” and “traffic violations”. The greater number of these type of incidents might be related to the growth in police enforcement measures during the first period after the redesigned road layout became operational. Attention should also be paid to incidents involving “a broken-down vehicle stopped on the road” that did not disappear during the period after the redesigned road layout became operational. This type of incident constitutes a special danger in view of the as-built cross-section of the road. Therefore, we recommend increasing police enforcement efforts to reduce such incidents along the redesigned road sections.

**3.2. After two years of operation**

Table 6 portrays the average vehicle transit speeds in total for all times of the day, in sub-sections of the redesigned road sections, during 2020, according to NTIC data. Figure 5 brings examples of the level of travel speeds for various hours of the day, in a number of sub-sections, per years of the monitoring effort. The findings showed that:

* Both in Section 1 and Section 2, the speeds in July and February 2020 were similar, while the travel speeds in 2020 were lower than those recorded in 2018. In most sub-sections, the speeds were stable throughout the daytime hours, with the following exceptions: on the Jerusalem-bound carriageway, the sub-section between the interchanges in Section 1 and in the vicinity of Shar HaGay Interchange, and on the Tel-Aviv-bound carriageway, in Section 2, unstable transit speeds were observed, during the daytime hours, with a broad range of changes.
* In Section 1, the representative levels of the transit speeds in 2020 were: in the sub-sections next to the interchanges, between 80–90 kph or between 90–100 kph, with an average value at all times of the day of 85, 90 or 95 kph (in different travel directions); in the sub-sections between the interchanges – between 70–110 kph (vehicles driving to Jerusalem) or between 90–100 kph (vehicles driving to Tel-Aviv), with an average daily value of 95 kph, in both travel directions.
* In Section 2, the representative levels of the transit speeds in 2020 were: between the interchanges, between 95–105 kph on the Jerusalem-bound carriageway, and between 70–100 kph on the Tel-Aviv-bound carriageway, with an average daily value of 100 kph and 80 kph, respectively; adjacent to the interchanges – between 70–80 kph on the Jerusalem-bound carriageway, and between 60–100 kph on the Tel-Aviv-bound carriageway, with an average daily value of 75 kph, in both directions.

Evaluation of the average speed within the representative speed ranges of the sub-sections during 2020 leads to an estimate of 88 kph. Similarly, calculation of the average representative speed at all times of the day provides a value close to 90 kph. Consequently, it emerges that the average speed level when transiting the redesigned road sections is close to the permitted speed levels prescribed for the as-built cross-section; therefore, there is no need to change the permitted speed limit defined for the new road layout.

Table 7 depicts concentrated data on traffic volumes and accident figures in the redesigned road sections in the two-year monitoring period compared with previous years. The findings pointed to an average increase of 17% in the traffic volumes two years after the redesigned road sections became operational, with representative traffic volumes of: 100,000 vehicles per day, in the “before” period, and 116,000 vehicles per day, in the "after” period.

As far as the occurrence of road traffic accidents is concerned, the following findings relate to the period in which the redesigned road sections became operational compared with the period beforehand: the annual average of the total number of road accidents with casualties was no different, while the percentage of severe road traffic accidents declined (p<0.05). Moreover, during the period after the redesigned road layout became operational more nighttime road traffic accidents were observed (p<0.05), and no significant changes occurred in the breakdown of accident categories. Examination of the rate of road traffic accidents in relation to exposure points to a (non-significant) decline in the period after the redesigned road layout became operational compared with previous years. An additional check of the changes in road traffic accidents occurring in the redesigned road sections compared with the control group did not reveal any significant changes. In total, during the second evaluation period too, no decline in the level of safety was observed in the redesigned road sections compared with the years prior to this.