Running head: Reducing speed using the left-digit effect

How to nudge drivers to reduce speed: The case of the left-digit effect

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WORD COUNT: 3,805
TABLES: 6
FIGURES: 0

Competing interests statement: The authors did not receive any funds for this study and do not have any competing interests to disclose.

Data statement: Data will be made available upon reasonable request to the authors.

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Abstract

To decrease the negative consequences of a road crash, even a small reduction in driving speeds can make a significant difference. This study examined the possible application of the left-digit effect as a nudge in order to reduce road speed. This effect is based on reporting price tags that are characterized by a low left-most number and a high right-most number (e.g., a price tag of €14.99 rather than €15.00). Participants were college students (43.75% female; mean age = 24.06 years in Study 1; 50% female; mean age = 23.53 years) who were asked to drive in a simulator on a route that had both usual unmodified road signs (e.g., 50 km/h) and the same road signs increased or decreased by one unit (e.g., 49, 51). The average median speeds held in road segments with unmodified road signs have been compared with those in the road segments with the corresponding modified signs. The average median speeds in the presence of a sign modified by the reduction of 1 km/h were significantly lower compared to the median average speeds recorded with unmodified signs. We showed that the application of psychological insights can reduce driving speeds and therefore increase road safety.

Keywords: Nudging, traffic psychology, left-digit effect, road safety, driving behavior

1. Introduction

Recent data showed that driver-related factors were present in almost 90% of crashes (Dingus et al., 2016). According to the World Health Organization (WHO, 2018), in 2016 road crashes were the eighth leading cause of death in the world and the first cause of injuries. Specifically, speeding contributed to around 30% of these deaths in high-income countries and up to 50% in some low-income and middle-income countries (WHO, 2018). For a comparison, 2017 data showed that, in the United States, 29% of crashes involved alcohol-impaired drivers (NHTSA, 2019).

Prior research has shown that increasing the speed limits can lead to higher travel speeds and an increased probability of exceeding the new speed limit resulting in a potential increase in fatal or injury crashes (Hu, 2017). Crucially, it has been shown that a 5% increase in average speed leads to an increase of about 10% in crashes that cause injury to people and a 20% increase in fatal crashes. Furthermore, pedestrians have a 90% chance of surviving if hit by a vehicle traveling at 30 km/h, but less than 50% if the vehicle travels at more than 45 km/h (WHO, 2018). Based on a recent study, the reduction of just one km/h would lead to an average reduction of 8.3% in fatal crashes (Elvik et al., 2019), which means saving up to 2,100 lives each year only in the European Union.

Numerous studies have been conducted over the years to find the causes of the different driving behaviors. For instance, it was found that male drivers tend to engage in riskier behaviors more than women, such as driving at greater speed or performing dangerous maneuvers (Evans & Wasielewski, 1983; French et al., 1993). Similarly, younger and less experienced drivers tend to risk more than those who are older or more experienced (Galin, 1981; Fildes et al., 1991). It has also been shown that, although the motivations to put oneself at risk vary from individual to individual, most drivers take risks unintentionally (Musselwhite, 2006) and, despite being aware of the dangers, many underestimate the risk associated with driving (Lichtenstein et al., 1978). Finally, prior work showed that psychological insights can explain the rate at which drivers comply with speed limits (Elliott et al., 2003).

It follows that an intervention that aims to reduce the risk of crashes must take into account the psychological and behavioral features of road users and, indeed, should focus on and take advantage of them to make the roads safer. Specifically, the goal of the present study was to test, using a driving simulator, an intervention based on behavioral science insights. Specifically, borrowing from marketing (Thomas & Morwitz, 2005; Manning & Sprott, 2009; Lin & Wang, 2017), we modified the speed limit information reported on usual road signs so that it could induce drivers to reduce their speed.

In this regard, behavioral science insights have become popular in recent years and provided valuable solutions to improve citizens' behavior (Halpern, 2016; Thaler & Sunstein, 2008). One of the main approaches in this field is nudging, a form of choice architecture that encourages individuals to adopt socially desirable behaviors, aimed at improving public health and individuals' well-being without limiting their freedom of choice (Thaler & Sunstein, 2008). In the field of road safety there are several nudge interventions that have been developed over the years. Some of these interventions are aimed at increasing safety levels by assisting the driver (the Advanced Driver Assistance Systems, or ADAS; Brookhuis et al., 2019). Other nudges take advantage of reward mechanisms, for instance a camera installed in Stockholm called "speed camera lottery" rewards drivers who respect speed limits with a cash prize derived from the fines of those who do not respect them (Zichermann & Cunningham, 2011). Finally, some interventions have been developed to increase road safety by applying perceptual countermeasures such as optical speed bars, raised rumbles, chevrons, or optical circles (Allpress & Leland, 2010; Hussain et al., 2018; Jamson et al., 2010; Martinez et al., 2013; Rossi et al., 2014). Nudges do not come without limitations and/or potential backfiring effects (Sunstein, 2017; Willis, 2013). For instance, the "speed camera lottery" may inadvertently cause an increase in traffic that could lead to other issues related to road safety or environmental issues. Despite this, however, this approach has shown very promising results and can be very useful when the interventions are tested and assessed beforehand to ensure that they do not produce any negative side effects (Thaler & Sunstein, 2008).

Our goal was to take advantage of the so-called left-digit effect, a strategy that typically belongs to marketing and use it to improve road safety. This effect is based on reporting price tags that are characterized by a low left-most number and a high right-most one (e.g., a price tag of €19.99 rather than €20.00). Several studies showed that a change in the left-most digit of a price significantly affects the perception of the magnitude (Thomas & Morwitz, 2005; Manning & Sprott, 2009; Lin & Wang, 2017). The explanation for this effect is based on the analogue model of numerical cognition (Thomas & Morwitz, 2005). The model suggests that multidigit numbers are converted into an analogue representation (Dahaene, 1997). Based on this view, when people read a multidigit number the leftmost digit exerts disproportionate influence on encoding. As a result, since an individual's cognitive resources are focused on left-most digit, the higher right-most one carries less weight in encoding. In the domain of pricing, this means that a $2.99 price is encoded as much lower than a price of $3.00 (Manning & Sprott, 2009).

Similarly, we modified the numbers on the road signs that indicate the speed limits. The objective was to alter the perception of the speed limit and make it feel inferior to what it actually was. We reduced the numbers on existing signs of a single unit, so that the left-most digit was reduced in turn (e.g., from 50 to 49 km/h). On a driving simulator, we then recorded the speed held by drivers in the presence of both these new, unusual signs, and the traditional ones. We hypothesized that, despite the minimal difference (1 km/h), driving speeds should be lower with the modified signs compared to the traditional ones.

2. Experiment 1

2.1 Method

2.1.1 Participants. Thirty-two college students (43.75% female; mean age = 24.06 years, SD = 1.56 years) voluntarily participated in this experiment. They had normal or corrected-to-normal vision and completed the study individually. All participants declared that they hold a valid driving license for at least 1 year. The chance to participate in the study was advertised in several course at both the engineering and psychology departments.

2.1.2 Materials and procedure. The experimental apparatus consisted of a dynamic driving simulator that has been validated in multiple previous studies (Rossi et al., 2018; Rossi et al., 2020). The main components of the dynamic driving simulator used for the present study included: i) three PC with Intel i7 processor, 3.4 GHz frequency, 2 DDR3 2 Gb RAM modules, Nvidia GeForce GTX 760 video card and Microsoft 7 Professional OS; ii) five 60” plasma displays with 1920x1080 pixel resolution, arranged side by side to cover a view greater than 300°; iii) a control display with keyboard and mouse for the operator; iv) a CKAS® mobile platform with the simulator cockpit on top, equipped with adjustable seat, safety belt, dashboard with ignition lock, steering, lever for turn signals and headlights, five-speed manual transmission and reverse gear, parking brake and pedal board with clutch, brake and throttle; v) a 5.1 surround sound system consisting of three front speakers, two positioned at the rear of the driver's head and a subwoofer located on the side of the pedal board.

The test procedure was structured into three different phases. In the first phase (familiarization), each participant was seated on the simulator and was invited to get into a normal driving position. Subsequently, a short driving session was started on a different track than the test one; this track was specially designed to allow the participants to become familiar with the simulator. The familiarization phase lasted about 5 minutes. In the second phase (driving test), the experimental track was then uploaded to the simulator and instructions were communicated to participants. They were asked to drive as similarly as possible to reality and not to talk to the experimenter except for retiring from the study. Each participant was also advised of the possibility of interrupting the test at any time (e.g., in case of nausea). Finally, after completing the driving test, participants completed the third part of the experiment (recall task) in which they were asked to perform both a spontaneous and a suggested recall of the experimental stimuli.

The driving route was characterized by very wide curves, alternating a curve to the left and a curve to the right. The road had two lanes and was a two-way street, with a constant width and without any road markings other than the edge and the center lines. The only road signs were those indicating the speed limits, positioned every 500 meters. The software was programmed in a way that, as the driver proceeded along the route, he/she encountered some vehicles all moving in the opposite direction but for one which was following him/her in the same direction. This vehicle respected speed limits, safety distances and could not pass the subject's vehicle.

The driving route was repeated three consecutive times for each participant, without pauses, in order to create the illusion of traveling a single 30 km road. In each 10 km repetition of the route, three different segments were identified. These segments had the following length and speed limit: 2 km with a limit of 70 ± 1 km/h, 2km with a limit of 50 ± 1 km/h, and 6 km with a limit of 90 ± 1 km/h. The 50 ± 1 km/h segment reproduced an urban road, whereas the other two segments reproduced suburban roads. Since the 10 km road was repeated three times, we were able to present each version of a speed limit (e.g., 49, 50, and 51 km/h) within-subjects. We counterbalanced the order in which each version of the speed limit was presented by creating four alternative forms of the track (see Table 1 for details).

Table 1. Pattern of road signs.

	Length of segments (km)								
	2	2	6	2	2	6	2	2	6
Track 1 signs (km/h)	70	51	89	71	49	90	69	50	91
Track 2 signs (km/h)	70	51	89	69	50	91	71	49	90
Track 3 signs (km/h)	70	49	91	71	50	89	69	51	90
Track 4 signs (km/h)	70	49	91	69	51	90	71	50	89

In order to have the same baseline and a common starting speed limit for all participants, we decided to have always the 70 km/h speed limit in the first 2-km segment of the track. Choosing a sign with a rounded speed limit for the first segment, like those commonly found in real life roads, allowed to make the start of the simulation look more realistic. The longest segment (6 km) was purposely associated with the highest speed limits (90 ± 1 km/h).

To assess whether the participants remembered (and therefore attended to) the signs encountered along the track, they were asked to complete two recall tasks: a spontaneous recall first and then a suggested recall. In the spontaneous recall task participants were asked to report the first three speed limits that they remembered from those seen during the test. In the suggested recall task 21 speed limits were shown: 9 of them were actually present in the track, while the other 12 were randomly chosen among signs that are present on real roads (e.g. 40, 60, and 80 km/h) or fictional (e.g. 39, 41, and 56 km/h). In this suggested recall task, participants were asked to mark all the limits that they remembered having encountered while driving on the simulator.

2.2 Results

The average speed recorded for each of the nine speed limits (i.e. from the first road sign indicating one of the speed limits to the first one indicating a different speed limit) was calculated for each participant. A Shapiro-Wilk test was conducted to assess the normality of the data. The data did not follow a normal distribution, therefore non-parametric tests (Kruskal-Wallis) assessing the equality of the medians for different groups were used for the analysis.

A first test was conducted to assess whether the order of presentation of the nine speed limits signs had an impact on the median speeds at which participants drove along each of the four tracks. Since the effect of order was not significant (always p = .06 or higher), we pooled together the data and did not include this variable in the following analyses.

To compare the speeds recorded for each of the signs we performed a series of one-tailed Wilcoxon tests. Specifically, we looked at changes in speed between the unmodified version of the sign and each of its two modified versions (e.g., 49 km/h vs. 50 km/h and 50 km/h vs. 51 km/h). This way, it was possible to assess, for each pair of signs, whether participants were slowing down significantly in correspondence of the lower speed limit or not.

Results showed that the median speeds in the presence of the 49 km/h sign were significantly lower than the median speeds in the presence of the 50 km/h sign, whereas there was no significant difference between the median speeds in the presence of the 50 km/h and 51 km/h signs. Similarly, median speeds were significantly lower when participants were presented with the 89 km/h sign than the 90 km/h one, whereas no significant difference emerged between speeds recorded for the 90 km/h and 91 km/h signs. Finally, when looking at the 70 km/h sign and its variations both differences were significant. In particular, participants drove at higher speeds in the presence of a variation (69 km/h or 71 km/h) than in the presence of the unmodified sign (see Table 2).

Table 2. One-tailed Wilcoxon tests.

		Wilcoxon with HP: less		Wilcoxon with HP: greater	
Speed limits	Median speed	*p* value	Z score	*p* value	Z score
49 km/h vs. 50 km/h	53.67 vs. 56.74	.021	-2.314	.980	-0.025
50 km/h vs. 51 km/h	56.74 vs. 56.16	.839	-0.203	.166	-1.387
69 km/h vs. 70 km/h	73.44 vs. 67.03	1	0	.002	-4.752
70 km/h vs. 71 km/h	67.03 vs. 71.21	<.001	-5.868	1	0
89 km/h vs. 90 km/h	84.25 vs. 85.54	.034	-2.121	.968	-0.041
90 km/h vs. 91 km/h	85.54 vs. 83.79	.844	-0.197	.160	-1.402

When looking at the two manipulation checks, we found that in the spontaneous recall task all participants correctly reported three speed limits. Answers to the suggested recall task showed that the new signs were reported by at least 62.07% of the participants (see Table 3), while no more than 20.69% of the participants reported a sign that was never presented.

Table 3. Percentages of suggested recall task.

Signs	49	50	51	69	70	71	89	90	91

% correct	62.07	65.52	72.41	65.52	37.93	65.52	79.31	65.52	86.21

2.3 Discussion

Our hypothesis was that participants would drive at lower speeds when presented with a road sign modified according to the left-digit effect (and therefore with the reduction of the speed limit by a single km/h) than when they were presented with the unmodified speed limit sign. The results showed significant differences for the road signs reporting a speed limit of 49 (vs. 50) and 89 (vs. 90) km/h, but not for the sign reporting a limit of 69 (vs. 70) km/h.

Since all participants begun the experiment seeing the 70 km/h sign in the first segment of the track and this is the only case in which our manipulation was not effective, we believed that the participants maintained lower speeds at the start because they had not acquired sufficient familiarity with the new track. To investigate this hypothesis, in Experiment 2 participants were presented with the 90 km/h sign (instead of 70 km/h) at the beginning of the tracks. As a result, in the new study we were able to test whether there was a difference between 69 and 70 km/h when this sign was not presented at the start of the tracks; similarly, we expected to find no effect for the 90 km/h.

3. Experiment 2

3.1 Method

3.1.1 Participants. Thirty-two college students (50% female; mean age = 23.53 years, SD = 0.59 years) voluntarily participated in this experiment. They had normal or corrected-to-normal vision and completed the study individually. All participants declared to hold a valid driving license for at least 1 year. The chance to participate in the study was advertised in several course at both the engineering and psychology departments.

3.1.2 Materials and procedure. By and large, the design for Experiment 2 was the same as in Experiment 1. However, we made a few changes to the placement of some of the speed limits. In Experiment 2, we switched the position of the 70 km/h and 90 km/h signs. Similarly, we switched the positions of the 71 km/h and 91 km/h signs as well as the position of the 69 km/h and 89 km/h signs. As a result, in this experiment, the first segment was always associated with the 90 km/h speed limit (see Table 4 for details).

Table 4. Pattern of road signs in the second experiment.

	Length of segments (km)								
	2	2	2	2	2	2	2	2	2
Track 1 signs (km/h)	90	51	69	91	49	70	89	50	71
Track 2 signs (km/h)	90	51	69	89	50	71	91	49	70
Track 3 signs (km/h)	90	49	71	91	50	69	89	51	70
Track 4 signs (km/h)	90	49	71	89	51	70	91	50	69

Since changing the position of the signs meant that speed limits in the final and longest segment were lower (with a consequent increase in travel time) than the previous study, the route has been shortened by 4 kilometers to reduce the possible influence that fatigue can have on participants' attentional resources (Gastaldi et al., 2014).

3.2 Results

The tests conducted on the data were the same as those of the first experiment. The Kruskal-Wallis test showed again that the order of the signs was not significant (always $p = .06$ or higher), so we pooled together the data and did not include this variable in the following analyses.

The Wilcoxon test showed that the median speeds in the presence of the 49 km/h sign were significantly lower than the median speeds in the presence of the 50 km/h sign, whereas there was no significant difference between the median speeds in the presence of the 50 km/h and 51 km/h signs, as in Experiment 1. Similarly, median speeds were significantly lower when participants were presented with the 69 km/h sign than the 70 km/h one, whereas no significant difference emerged between speeds recorded for the 70 km/h and 71 km/h signs. Finally, when looking at the 90 km/h sign and its variations, both differences were significant. In particular, participants drove at higher speeds in the presence of a variation (89 km/h or 91 km/h) than in the presence of the unmodified sign (see Table 5).

Table 5. One-tailed Wilcoxon tests.

		Wilcoxon with HP: less		Wilcoxon with HP: greater	
	Median speed	*p* value	Z score	*p* value	Z score
49 km/h vs. 50 km/h	60.21 vs. 62.48	.008	-2.660	.993	-0.009
50 km/h vs. 51 km/h	62.48 vs. 62.76	.825	-0.221	.180	-1.341
69 km/h vs. 70 km/h	70.34 vs. 73.55	.026	-2.226	.975	-0.031
70 km/h vs. 71 km/h	73.55 vs. 73.94	.562	-0.579	.445	-0.764
89 km/h vs. 90 km/h	85.50 vs. 76.40	1	0	<.001	-5.918
90 km/h vs. 91 km/h	76.40 vs. 86.74	<.001	-5.918	1	0

When looking at the two manipulation checks, we found that in the spontaneous recall task all participants correctly reported three speed limits. Answers to the suggested recall task showed that the new signs were reported by at least 56.25% of the participants (see Table 6), while no more than 12.50% of the participants reported a sign that was never presented.

Table 6. Percentages of suggested recall task.

Signs	49	50	51	69	70	71	89	90	91
% correct	81.25	50.00	78.13	71.88	59.38	62.50	81.25	53.13	56.25

3.3 Discussion

Experiment 2 replicated the previous finding showing that participants significantly reduced their speed when presented with a sign one unit lower than the usual one (e.g., 49 vs. 50 Km/h). In addition, we were able to show that the lack of an effect for the 70 km/h sign (and its variation) in the first experiment was likely due to its positioning in the first section of the track. Consistent with this explanation, in Experiment 2 we did not find a significant effect for the 90 Km/h sign (and its variation) which was now placed in the first section of the track, replacing the 70 Km/h sign.

4. General discussion

The main purpose of this research was to assess the effectiveness of the left-digit effect as a nudge to improve road safety. Our hypothesis was that the participants would go at lower speeds in the presence of a road sign modified according to the left-digit effect compared to any other difference of a single km/h that does not involve the aforementioned effect.

Both experiments confirmed this hypothesis regarding the 50 km/h sign. Experiment 1 also confirmed this hypothesis regarding the 90 km/h sign and Experiment 2 confirmed it regarding the 70 km/h sign. As for the 70 km/h signs in the first experiment and the 90 km/h signs in the second one, the effect was likely not significant because they were positioned at the beginning of each of the four tracks. The positioning of these signs was decided to keep constant for all participants the initial speed limit and to make the simulation more realistic. This could have led participants to drive more prudently in the presence of these signs because they were not yet familiar with the route. Despite participants having a chance to familiarize with the simulator, results seemed to indicate that they started the experiment driving at a speed much lower than the limit (unlike in following segments of the route). An alternative explanation could be that participants were particularly attentive to the speed limits when they had just started the simulation. At that point they had not reached enough confidence with the simulator and were more focused on the cues on the road than on simply driving as they would do in real life. However, this explanation is not supported by the results of the recall task, since in both studies the signs presented in the first segment (70 km/h in Study 1 and 90 km/h in Study 2) are those that were recalled the least often.

Crucially, from the data emerges that the median speed maintained by the subjects in the presence of signs modified with a decrease of 1 km/h is significantly lower than the median speed maintained in the presence of the corresponding unmodified signs. In addition, the median speed maintained in the presence of signs modified with an increase of 1 km/h was not significantly different than that maintained in the presence of corresponding unmodified signs. The different pattern of results that was found by modifying speed limits by +1 versus -1 km/h is extremely important because it allows to conclude that it is not the gap in speed limit that drives the effect. Indeed, it is the left-most digit that makes people perceive the limit as lower and therefore leads them to slow down. Otherwise, we should have found a difference in speeds even when the limit on the sign was increased by 1 Km/h.

In the recall task, participants were proficient at recalling both signs that were 1 km/h above (e.g., 51 km/h) or below (e.g., 49 km/h) a usual one (e.g., 50 Km/h). This was expected since these signs are unusual and therefore should attract people's attention, something that has been proved to make them easier to recognize (Gregory et al., 2016). However, the results of our driving simulation were not consistent with an explanation simply based on unusual information, since people were more likely to change their speed when the sign was 1 km/h below the usual one rather than 1 km/h above it.

The present study showed a reduction in driving speeds that is comparable to what has been found in the literature using perceptual countermeasures (Jamson et al., 2010), especially when considering that we had participants drive on a road with long sweeping curves and no traffic. Future work should investigate the combined effects of our modified signs with other perceptual cues to assess whether these two measures can help treat sections of road with long straights or a long radius corners in which drivers find more difficult to reduce speeds. Still, we believe that an important contribution of our work, and a significant difference with the literature on perceptual countermeasures, is that signs can be repeated often along the road. In contrast, many perceptual cues cannot be used on long stretches of road or may take up too much room on the road (e.g., central and peripheral hatching). As a result, these solutions can work well in specific sections of the road (e.g., near schools, in the presence of road work, or before a dangerous curve). Our work showed that modifying the speed signs could be a way to make them more effective and this could help extend the length of road sections in which an intervention to reduce speed can be implemented.

Although the results of the present experiments are very promising in terms of finding a simple and effective way to make drivers reduce their speed, some limitations must be acknowledged. A first limitation is that we run the experiments on a simulator. Despite being quite realistic, the simulation lacked some of the complexity that characterizes real world roads. As a result of this limitation, it is hard to understand whether this nudge intervention may have unwanted side effects or produce a backlash from road users once introduced in real life. However, consistent with the general criteria behind good nudges (Thaler & Sunstein, 2008), we want to stress that this is just an initial evidence of the effectiveness of the left-digit effect applied to speed limits. Real life tests in specific conditions (e.g., close to a school or in the presence of road works) or in short sections of roads are needed to make sure that this nudge works and does not cause unexpected and potentially unsafe behaviors. This would also be a way to assess the effectiveness of the intervention and whether it is applicable in light of the well-established procedures used to set speed limits.

In accordance with the above reasoning, a second limit is that it could be unrealistic to think that a town council or country could modify all signs to implement this type of nudge. It would likely be very expensive to do such an intervention. However, it could be trialed out first in a small environment such as a single neighborhood or a small town and then extended, if the results justify the investment. A way that could make this intervention more cost-effective, flexible, and implementable in a short to mid-time horizon, would be to place digital signs on the roads indicating the modified speed limit.

Finally, our work does not allow any conclusion as to the effectiveness of this nudge overtime. In other words, it is not clear whether the intervention we tested will last even once the drivers are used to the new signs. A first test could be done running in the simulator several experimental sessions with the same participants. This would make possible to assess if people after a while get used to the signs and start not paying enough attention to them. Based on literature on the left-digit effect in marketing, we can establish a testable hypothesis and expected results. If, after quite some time, price tags with a leftmost digit lower than the rightmost one (i.e., $19.99) are still effective, then we should expect to find a similar result with the modified road signs as well.

5. Conclusions

The present work shows that the left-digit effect can potentially be used to modify driving behaviors, precisely to impact the speed at which people drive. This relevant result is consistent with the nudge approach since it did not force drivers to go slower or impose any cost to them. Therefore, from an applied point of view, the speed differences that emerged in our experiments when the sign was reduced by 1 km/h are extremely relevant and could make a huge difference in terms of the consequences of an crash. Indeed, by reducing participants' speed, we achieved a goal that previous research showed it could reduce significantly the number of fatal crashes on the roads and save thousands of lives yearly (Elvik et al., 2019).

Much efforts and investments have gone into campaigns aiming at making drivers aware of the negative consequences of driving too fast. However, these campaigns have often fall short of reaching the goal of reducing the speed at which people drive. In the present work, we showed an alternative way to reach the same objective by simply modifying a set of information that is already present along all roads.

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