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Dynamic travel information strategies in advance traveler information systems and their effect on route choices along highways

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Abstract

Advance Traveler Information Systems (ATIS) inform drivers about traffic incidences and expected travel times/ delays en-route. An online computer study was conducted in Qatar to investigate drivers' willingness to divert to an alternative route given changes in expected travel conditions. Respondents' route choices were queried after exposure for 6 seconds to varying display strategies. The results from a binary logistic regression and a stated preference survey showed that delay times and displayed colors on a Graphical Route Information Panel (GRIP) effectively influence drivers to take the alternative route, while total travel times were preferred for Variable Message Signs (VMS).

Keywords: VMS; GRIP; Dynamic Travel Information; Time; Delay; Route Choice

1. Introduction

Peak travel congestion and the occurrence of traffic incidents such as road works and crashes increase delays and total travel times on the road network. Providing dynamic travel information (DTI) on the highways is, therefore, important to inform drivers about the real-time traffic conditions to their destination. Redirecting a certain number

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of drivers via alternative routes to make use of the entire road network during peak travel times can improve the overall travel times and reduce the congestion pressure on the highway network. Advanced traveler information systems (ATIS) are promising technologies to predict and manage travel times of drivers to make road transport more reliable [1] [2]. ATIS provide route-specific information and convey real-time information to the drivers that help them to better plan or adjust their journey. Two types of dynamic LED-display systems are currently in use: First, Variable Message Signs (VMS) displaying dynamic text information and warning pictograms. They are commonly employed in many countries around the world, including the State of Qatar. Second, Graphical Route Information Panels (GRIP) can visualize the route network and linked destinations while also displaying warning pictograms and congestion locations using colors [3]. The first GRIP's were tested in 1999 in Japan and have since then been increasingly implemented in western countries [4]. Qatar has a very heterogeneous driver population with only 10% of Qatari and a large variety of other nationalities [5]. This raises a lot of challenges for road authorities to identify most effective strategies to inform drivers on the highways. Furthermore, the development and extension of road infrastructure is progressing since Qatar is hosting the FIFA World Cup in 2022. In line with this, travel and work VISA policies have been adjusted, which will contribute to an increase in travel demand [5]. The road authorities have to decide which information format and display type should be employed to influence drivers' willingness to divert from the initial route in case of traffic hinder. Therefore, the goal of this study is to investigate drivers' route choices under varying traffic incidences being displayed according to best practice designs. It is required to determine whether available ATIS configurations are well comprehended and suitable for implementation on highways in countries like Qatar that are characterized by (or periodically expect an increase in) international drivers. Displaying effective traffic messages is, therefore, crucial to elicit the desirable traffic distribution that can optimize the road network capacity in case of congestion formation.

1.1. Dynamic Travel Information

Travel times, travel speed, distance, delays, and information about incidents on the roadway can be displayed on both VMS and GRIP. The information is given for the main travel route to a destination but can also include advisory messages to follow an alternative route at strategic interchange locations [6]. The information can address total travel times as an indicator for journey planning [7] [8]. On the other hand, specific delay times are displayed in combination with incidents on the road (e.g. congestion, road works or crashes) [9] [10]. The updated DTI (using a delay or travel time display) can put the driver in a state where he/she has to re-evaluate the previous intended route to a specific destination and consider taking an alternative route. A study investigated the route choice of U.S. drivers in case VMS were activated to inform drivers about an alternative route. The study found that for a VMS to be effective, at least the expected delay and the best detour strategy should be shown [11]. When the delay time was shown in minutes, people were more likely to change routes [9]. Other research did apply the estimated travel times for each route to test drivers' route choices in combination with changing information accuracy [12]. Furthermore, the presence of a pictogram on the nature of the delays (general congestion, crash or road works) also had a significant influence on drivers' comprehension and sensitivity to divert [9]. These results were further validated by findings indicating that drivers were more likely to change routes when presented with additional information on the length and nature of the delay [13]. Drivers were found to be more willing to divert routes if the cause of the delay has a more severe connotation such as an accident warning [14]. Research has highlighted that the driver's diversion behavior is influenced by familiarity and traffic conditions on the alternative route, as well as confidence in the information. Still, a certain group of drivers will remain undecided [15]. Comparing delay times on two routes or comparing the total travel times of these routes can elicit different responses depending on the familiarity with the normal travel time and the overall travel distance. In a recent study, drivers of a test group were more likely to choose the slower shorter route when the longer route was shown to actually save time, which indicates the importance of travel distance as compared to time [16]. The same study also highlighted the beneficial effects for applying the gain frame for the alternative route and the loss frame for the main route at equal travel times [16]. Communicating the delay spend in congestion (loss frame) may influence the route choice of drivers seeking the faster or undelayed route. Time spent in congestion may have a larger perceived disadvantage as compared to taking a longer alternative route with equal or less total travel time. The real-time DTI should be updated to maintain credibility and provide enough information for drivers to weigh the benefits and risks of taking an alternative route to their destination [17]. The displayed information has to be correctly comprehended within short exposure time while driving. A previous study highlights the risk of incorrect interpretation indicating that drivers did not know if a travel time referred to the total travel time or the delay time [18]. Moreover, studies have shown that variations in possible travel times and low accuracy of displayed information make drivers prefer the main route, accepting a possible loss and refusing to change to the faster (but longer) route [12].

1.2. Design guidelines of VMS vs. GRIP

Guidelines for VMS use recommend displaying a maximum of 3 information lines on highways [19]. Drivers have only a limited amount of time available to view and read the displayed DTI on a VMS (up to 6 seconds when driving highway speeds) [18]. While GRIP's can be used for most of the same strategies as VMS, they have additional advantages such as displaying information about the road network with the aid of a graphical map [20]. Several studies have shown that, when at least two routes are presented with different travel times due to congestion, drivers would be more likely to pick the faster, non-delayed route [18]. When using a graphical map of a route network, the direction of the network has to be clear to the driver. Studies have found head-up displays (downstream route at top of the panel) to be the best for fast orientation from the drivers' perspective [21]. The advantage of GRIP is the usage of colors to show congestion and slow traffic on the graphical map. Existing studies have often used red to highlight congested roads against black, or no color [18]. Overall, the red congestion color has provided the best results in terms of comprehension [13]. Other colors have also been used, as for example green to indicate the optimal route or a free-flow traffic condition. Yellow/orange has been used to indicate the occurrence of slow traffic. Additional pictograms on the GRIP improve the comprehension of the delivered congestion message, but can also increase the overall viewing and comprehension time to 10-15 seconds in case of unfamiliarity with GRIP [22] [1]. Research has also been done regarding the use of different geometric representations of the road network. Map shapes similar to the natural road network are appreciated among drivers [13]. However, in a Belgian study, drivers were better able to verify specific travel statements when being exposed to an abstract instead of a naturalistic route map on the GRIP [23]. In a Chinese study, triangles were found to be better understood than rectangles [1]. Overall, the necessary response times for GRIP were 4-6 seconds for a good understanding of the majority of drivers [18].

2. Objectives

Several best practice designs for VMS and GRIP have been identified from the literature [4][6][19]. Nevertheless, it remains unclear for road authorities aiming to invest in ATIS whether VMS or GRIP differ in effectiveness for information provision and how to employ them for varying traffic rerouting purposes. Time displays in minutes (e.g. total travel time, delay time, or regular travel time plus delay) for the original and an alternative route, as well as the inclusion of a pictogram displaying the nature of the delay on the original route can help drivers to make an informed route choice. Still, more research is required to determine the contribution of design factor combinations on drivers' understanding of the situation and the consequential route choices. Also, the perceived time/delay threshold that motivates drivers to divert from the route can depend on the travel circumstances. Therefore, the aim of this study is fourfold: 1.) determine drivers delay and time sensitivity on free and work days, 2.) test drivers' route choices under limited ATIS viewing time, 3.) investigate drivers' comprehension of time display methods on VMS and GRIP, and 4.) inspect drivers' preferences for specific configurations.

3. Method and Procedure

An online link to the Qualtrics data collection website that covered demographic questions, a time sensitivity survey, a route choice and comprehension task, and a final stated preference survey was distributed via email to the students and staff of Qatar University. Moreover, respondents from the general driving population were recruited via social media platforms in Qatar. A within-subject design was applied to let the respondents evaluate all 18 design scenarios. An orthogonal design for conjoint attributes was applied to reduce the possible attribute combinations per information panel. This reduced correlations between the designs and left us with 9 attributes for VMS and 9 for GRIP. The study consisted of five parts: 1.) An introduction to the context of the research was provided. The participants were asked to sign an informed consent form and were informed about the fact that they could abort the online study at any time. 2.) A demographic questionnaire was presented that was followed by a driving and time sensitivity questionnaire asking respondents when they would divert when being confronted with a specific delay or change in travel time on workdays and free days. 3.) A practice session with a VMS and GRIP display example was presented to familiarize the participants with the limited exposure time, the type of displays and the nature of questions they had to answer afterwards. 4.) Route choice and comprehension test: VMS or GRIP designs were randomly displayed for 6 seconds before auto-advancing and asking the respondent whether he/she would stay on the original route or take the alternative route to the destination. Afterwards, the display was shown a second time for 6 seconds followed by comprehension questions about the two routes. The respondent was again asked to indicate his/her route choice. 5.) The stated preference survey required the participants to evaluate the two DTI formats (VMS and GRIP) in combination with three types of time displays (total travel time, delay times or regular travel time plus delay) and three incident warnings (crash, road works, congestion) on a 5-point Likert scale. They also had to select their preference for a time display method. In total, 114 respondents filled out the questionnaire about the demographic background and time sensitivity on workdays and free days. However, 44 participants did not complete the entire test battery leaving us with a final sample of 70 for the route choice test and stated preference survey.

4. Results

Table 1. Demographics of 114 respondents

Gender:	Origin:		Profession:		Driving license ownership	
Male: 85	Arabs	45%	Employed full time	28.9%	> 2 years	85%
Female: 30	Western	13%	Employed part-time	5.3%	< 2 years	9%
Age	Asian	31%	Unemployed	6.1%	Probationary	6%
Range 18-59 years	African/American	11%	Student	57.9%		
Mean 26 years SD 9 years			Housewife/househusband	1.8%		

4.1. Time sensitivity

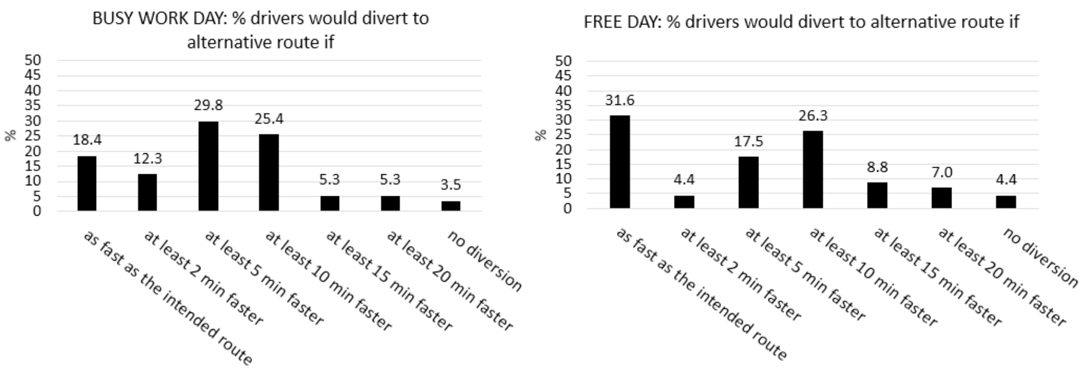


Fig. 1. Stated travel time-sensitivity of 114 respondents (a) travel time busy workday (b) travel time free day

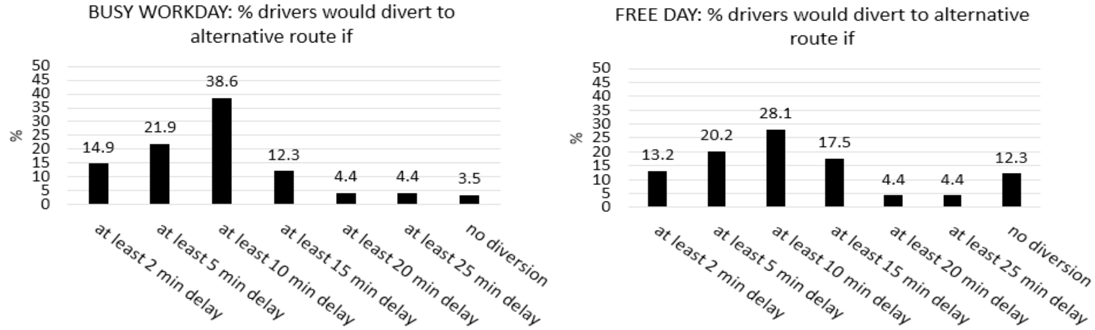


Fig. 2. Stated delay time-sensitivity of 114 respondents (a) delay time busy workday (b) delay time free day

The demographic background of 114 respondents is summarized in Table 1. The sample resembles the diverse driver population in Qatar with 45% Arabs, including Qatari. The time sensitivity analysis revealed that drivers would divert on a busy workday if the alternative route is at least 5 min (29.8%) or 10 min (25.4%) faster (Fig. 1a). On a free day, drivers would take the alternative route if the displayed total travel time is as fast as the original route (31.6%) or at least 10 min faster (26.3%) (Fig.1b). When it comes to displayed delay times, the respondents answered that they would divert to the alternative route on a busy workday if the original route has at least 10 min delay (38.6%) (Fig. 2a). In the case of a free day, the results were more distributed and most drivers (79%) indicated to divert to the alternative route if there was up to 15 min delay displayed for the original route (Fig. 2b).

4.2. Diversion rate before and after comprehension test

Table 2 presents the results of the route choice test of 70 respondents after a 1st and 2nd six seconds exposure including comprehension questions. It was shown that the initial diversion rate based on the displayed designs was very similar to the confirmed route choice after active comprehension. This indicates that all designs were already well understood after the first exposure, which is similar to the 6 seconds viewing time when travelling at highway speeds. Interestingly, the time display methods for work zone resulted in big variations in the diversion rate being as low as 48.6% - 52.9% for regular time plus delay and as high as 92.9% - 97.1% for delay times.

Table 2. Route choices of 70 respondents

	VMS	Initial diversion rate %	Confirmation diversion rate %	GRIP	Initial diversion rate in %	Confirmation diversion rate %
1	Accident_delay	91.4	92.9	Accident_red_delay	97.1	97.1
2	Congestion_total	44.3	45.7	Congestion_red_total	50	50
3	Workzone_regular&delay	48.6	48.6	Workzone_red_regular&delay	52.9	61.4
4	Accident_total	94.3	94.3	Accident_redgreen_total	92.9	91.4
5	Congestion_regular&delay	87.1	94.3	Congestion_redgreen_regular&delay	92.9	92.9
6	Workzone_delay	92.9	94.3	Workzone_redgreen_delay	97.1	98.6
7	Accident_regular&delay	87.1	90	Accident_redorange_regular&delay	80	81.4
8	Congestion_delay	85.7	92.9	Congestion_redorange_delay	90	92.9
9	Workzone_total	84.3	81.4	Workzone_redorange_total	84.3	82.9

4.3. Design Factors influencing the probability of diversion

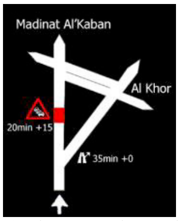
A binary logistic regression analysis was performed with Bonferroni correction to investigate the impact of each design factor on route choice. The results were summarized in Table 3. Positive B values indicate the design factors that contributed to taking the alternative route. Nagelkerke R^2 for effect size indicates an explained variance of 19% due to the design factors. The results of the model show that total travel time was a significant factor in taking the alternative route. In comparison, delay time increased the probability of taking the alternative route by 3.624. In contrast, the regular time plus delay display did not significantly affect the likelihood of respondents to divert from the original route. When we look at the reason to divert it becomes clear that congestion is a significant reason to take the alternative route. In comparison to that, displaying a crash pictogram would significantly increase the probability to divert from the route by 3. In contrast, the road works pictogram was not significantly increasing the probability to take the alternative route. Interestingly, the GRIP format, in general, was significantly decreasing the probability of diversion by 55% as compared to the VMS, which can be attributed to the fact that the longer distance of the alternative route is displayed by the map. However, when looking at the colors on the GRIP separately, they appear to significantly influence the decision to take the alternative route. In comparison to displaying the color red only, an additional color green on the alternative route increased significantly the probability to take the alternative route by 8.117. Also, the color combination red-orange did significantly affect drivers to choose the alternative route as compared to red only, although to a lesser extent as compared to red-green. This indicates that colors work well in distinguishing the two available routes and that green is well understood to represent the faster traffic conditions.

Table 3. Binary logistic regression for display factors influencing the probability of diversion

Display factors	B	S.E.	Wald	df	p-value	Exp(B)	95% CI for EXP (B) Lower	95% CI for EXP (B) Upper
Total travel time			43.690	2	.000			
Delay time	1.288	.222	33.636	1	.000	3.624	2.346	5.600
Regular time plus delay	-.129	.172	.566	1	.452	.879	.628	1.230
Congestion			29.481	2	.000			
Crash	1.128	.212	28.410	1	.000	3.089	2.040	4.676
Road works	.233	.177	1.736	1	.188	1.262	.893	1.784
GRIP	-.598	.190	9.899	1	.002	.550	.379	.798
Color_red			39.565	2	.000			
Color_red-green	2.094	.346	36.536	1	.000	8.117	4.117	16.007
Color_red-orange	.848	.256	10.945	1	.001	2.334	1.413	3.857
Constant	.697	.161	18.635	1	.000	2.007		

Significance level $\alpha < 0.05$

4.4. *Stated Preference for display time during adjusted GRIP color phases*



a) Ph. 1: regular & delay

b) Ph. 2: total travel time

c) Ph. 3: delay time

Fig. 3. a) b) c) GRIP phases designs

Table 4. Paired differences GRIP phase 1, 2 & 3

		Mean	Std. Deviation	Std. Error Mean	95% CI Lower	95% CI Upper	t	df	p-value
Phase 1	Total travel times vs. delay	1.000	1.551	.185	.630	1.370	5.394	69	.000
	Total travel times vs. regular & delay	.086	1.349	.161	-.236	.407	.532	69	.597
	Delay vs. regular plus delay	-.914	1.432	.171	-1.256	-.573	-5.342	69	.000
Phase 2	Total travel times vs. delay	.086	1.004	.120	-.154	.325	.715	69	.477
	Total travel times vs. regular & delay	-.229	1.194	.143	-.513	.056	-1.602	69	.114
	Delay vs. regular plus delay	-.314	1.198	.143	-.600	-.029	-2.194	69	.032
Phase 3	Total travel times vs. delay	.214	1.089	.130	-.045	.474	1.647	69	.104
	Total travel times vs. regular & delay	-.314	1.357	.162	-.638	.009	-1.938	69	.057
	Delay vs. regular plus delay	-.529	1.248	.149	-.826	-.231	-3.544	69	.001

Respondents were asked to evaluate the DTI on a GRIP on how convincing it was to take the alternative route to their destination using a Likert scale with 1 (completely agree) to 5 (completely disagree). Rerouting messages were updated in three phases (informative, persuasive and accurate) to display congestion occurrence (see Fig. 3 a,b,c). In the first phase, congestion is forming on the original route. The displayed travel time for the alternative route is as long as for the original route (informative). In the second phase, the congestion on the original route increases and the drivers get "nudged" by the green color representing free traffic flow to follow the alternative route (persuasive). During the third phase, the congestion on the original route remains stable, whereas 'rerouting' drivers has naturally increased the traffic volume on the alternative route. The orange color indicates slower traffic for a particular road segment that causes 3 min delay (accurate). The GRIP is updated accordingly to increase the credibility of the traffic information. The results of the stated preference survey are shown in Table 4. The paired differences for displayed travel times in phase 1 revealed that there is a significant difference in means between total travel times and delay times with a higher probability to take the alternative route if delay times are shown. There was no significant difference between displaying total travel times or regular travel times plus delay since drivers would calculate the latter display to total travel times. Instead, there was a significant difference between delay times and regular times plus delay with a higher willingness to take the alternative route if delay times are presented. The differences in means for GRIP phase 2 show only a significant difference between delay time display and the regular time plus delay display. More respondents agreed to take the alternative route if delay times are displayed in combination with the green color indicating free traffic flow. In phase three, the traffic volume on the alternative route has increased and the orange color indicates slower traffic for a particular road segment. For this phase, there was a significant difference between delay and regular time plus delay indicating that respondents were only convinced to take the alternative route if delay times are displayed.

4.5. Stated preference for time display in combination with VMS warning pictogram

Respondents had to indicate which time display method they preferred in combination with a displayed warning pictogram (crash, road works, congestion) on a VMS. Fig. 4 indicates clearly that the display of total travel times is mostly preferred for all warning purposes as compared to the other time display methods. Delay times were evaluated slightly better for road works and regular plus delay was only appreciated for congestion warning.

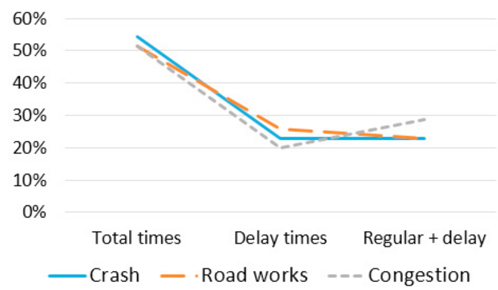


Fig. 4: Preference for time display method for each warning

5. Discussion and Conclusion

This computer study revealed that drivers from an international sample in Qatar were willing to divert from their route if the alternative would be 10 min faster or if delay times would be 10-15 min. These findings are fairly comparable with the literature [24]. Furthermore, it was shown that the tested VMS and GRIP layouts for similar combinations of time display methods and warning pictograms resulted in comparable diversion rates before and after a second viewing time of 6 seconds. Both, GRIP and VMS were comprehended well at first exposure. However, considering the fact that driving is a complex task that does not allow for perfect viewing conditions as compared to this computer test, the study will be replicated with a selected subset of test designs in a driving simulator or on-road. This study found that the display factors influencing the probability of taking the alternative route were total travel times and delay times but not regular time plus delay. In particular, delay times performed best in increasing the diversion rate, which is supported by the literature [24]. Interestingly, respondents stated to prefer delay times on GRIP, but total travel times on VMS to make an informed route choice. In line with the literature, crash warnings increase the probability of diverting to the alternative route [14]. A road works warning would not convince drivers to divert from the intended route. However, in combination with displayed delay times, the diversion rates for road works were highly increased, which is an important finding suggesting that changes in display configurations affect drivers' route choices in case of road works. Also, the use of two colors visualizing the location of congestion on the road map while providing contrasting color information for the alternative route did effectively encourage drivers to take the alternative route. However, the GRIP map also visualizes the longer distance of the detour as compared to the current route. This distance information is not explicitly transmitted with a VMS that displays dynamic travel times only. Despite the fact that total travel times might be more straightforward in terms of information provision, delay times have a better overall effect on influencing rerouting behavior and should be considered for display during peak travel times before highway sections with extensive road works. Future studies with larger sample sizes are recommended to further validate these findings.

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