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The influence of variable message signs on en-route diversion between a toll highway and a free competing alternative

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Abstract
In the field of road transport, Advanced Traveller Information Systems represent a relevant tool to manage road traffic, improve drivers' utility and make a more efficient use of transport infrastructure. Due to the growing sources of en-route information available nowadays, it is crucial to understand better its influence on drivers' behaviour, particularly with regard to route choice. Previous research in this field has mainly focused on the provision of en-route information in toll-free environments. However, few researches have explored its influence when a tolled alternative is available. This paper is aimed at exploring the influence of variable message signs (VMS) information on drivers' route choice, made between a free highway and a competing tolled alternative. To that end, we develop a binary logit analysis based on empirical data from the metropolitan area of Madrid, Spain. Results show that the type of information provided to drivers through VMS panels significantly influences their route choice when one of the alternatives is tolled. Furthermore, some combinations of messages, such as adding travel time estimates together with incident messages, greatly increase the diversion rate to the tolled route. The research also offers evidence that the influence of the information provided changes according to the type of day, which may be related to traffic conditions, and to the different types of user characteristic of weekday and weekend mobility.

Keywords Advanced traveller information systems · Route choice · Route diversion · Toll road · Variable message sign

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Introduction

Within the framework of Intelligent Transport Systems (ITS), Advanced Traveller Information Systems (ATIS) provide travellers with real-time information about transport conditions in an attempt to create a more efficient use of transport infrastructure. ATIS can represent a powerful tool to improve the performance of drivers and transport networks (Abdel-Aty et al. 1997; Chatterjee and McDonald 2004) by, for example, increasing travel time savings and enhancing travel time reliability (Toledo and Beinhaker 2006). From the perspective of traffic managers, one of the most interesting applications of ATIS is the possibility of influencing on route diversion, from congested roads towards alternative itineraries, thus mitigating queues caused by non-recurrent incidents.

Depending on the time when the information is received by the traveller, systems may be classified as en-route or pre-trip information. It is widely acknowledged that both approaches reinforce each other with respect to route choice since Abdel-Aty and Abdalla (2004) corroborated that adding en-route information to pre-trip information increases route diversion. Tsirimpa et al. (2007) confirmed that pre-trip information is more focused on changing departure time, whereas adding en-route information reduces departure time dependency. En-route information is gaining importance due to the increase in new channels available to drivers for getting this information through, for example, in-vehicle devices and mobile traffic applications. Nevertheless, variable message signs (VMS), also called dynamic message signs or changeable message signs, likely represent nowadays the most widespread tool available for traffic managers and policy makers to provide en-route information to drivers. VMS are panels installed on the roadside or above the road, which display information about downstream traffic conditions. Practical examples on the use of VMS to provide route suggestions can be found in urban areas of, for example, China (Zhong et al. 2012) and Korea (Li et al. 2015). Therefore, it is important to explore in greater detail the role played by this type of information.

The vast majority of studies analysing the influence of ATIS—particularly, the use of VMS—on route choice behaviour are focused on toll-free environments. Petrella and Lappin (2004) found that the satisfaction and the degree of compliance with transport information depend on the regional and traffic characteristics of the location. Additionally, in a review of VMS effectiveness in nine European cities, Chatterjee and McDonald (2004) demonstrated that diversion rates depend on the specific location of the panel as well as infrastructure conditions. Therefore, the effectiveness of VMS in promoting route diversion may vary when one of the available itineraries is tolled.

This research is aimed at exploring the impact that real-time information has on drivers' route choice between a free highway and a competing tolled alternative, with a special focus on the information provided through variable message signs (VMS). To that end, we perform an empirical analysis in which diversion rate data are obtained from loop detectors in the metropolitan area of Madrid (Spain). It is an appealing case study in the international context because the Spanish high capacity network usually includes toll and non-toll roads competing within the same transport corridor. Hence, toll sections generally have excess capacity whereas drivers in toll-free sections experience congestion during peak hours. This imbalanced distribution of road traffic between both available alternatives could be improved if drivers were provided with relevant and updated information about real traffic conditions.

This paper contributes to the current literature in several aspects. Firstly, it sheds light on the impact of ATIS on route diversion between a toll-free highway and a competing tolled alternative, an issue barely explored up to date. Secondly, while many of the previous studies on the impact of ATIS on route choice behaviour are based on simulations or questionnaires, this research is based on field data. Furthermore, the selected case study, the Spanish road network, presents singular conditions and implications that are worth exploring and potentially extrapolated to other countries.

This paper is organised as follows. After the "Introduction" section, "Literature review" section reviews the state of knowledge concerning route choice when real-time information is provided, with a particular emphasis on the performance of VMS. "Case study and data collection" section describes the case study selected, and the data used for the research, justifying their suitability. "Methodology" section establishes the methodology, and "Modelling results and discussion" section presents and discusses the results. Finally, "Conclusions and recommendations" section draws the main conclusions and proposes further research questions.

Literature review

VMS covers a wide range of utilities in demand traffic management. In the last two decades, many research studies have explored its performance in multiple areas such as: safety and the decrease of speed in work zones (see e.g. Ahmed et al. 2016; Huang and Bai 2014), the effectiveness of safety campaign messages (e.g. Chaurand et al. 2015; Jamson and Merat 2007), the improvement of road safety in case of adverse weather or visibility conditions (Hassan et al. 2012; Rämä and Kulmala 2000), and in-car variable message signs focused on eco-driving (Niu and Sun 2013).

Until now, there has been a wide literature regarding the influence of VMS on drivers' behaviour, particularly concerning route choice. Previous contributions, focused on toll-free environments, have shown that the diversion rate due to VMS presents large variations depending on the case study. Foo and Abdulhai (2006) concluded that a change in VMS could vary the diversion rate up to around 5% on average, following a decreasing trend over time. For the case of Oslo, Erke et al. (2007) determined a guidance compliance rate of about 20% based on traffic counts. Furthermore, Schroeder and Demetsky (2011) analysed diversion rates based on seasonal and hourly variations, incident type, and the content and the format of VMS. These authors found higher diversion rates during summer and non-peak hours, while the lowest diversion rates occurred during the afternoon peak hour.

The degree of influence of VMS on drivers' behaviour may be influenced by different factors. Regarding the content and the extent of the message provided, Wardman et al. (1997) found that messages about accidents have the biggest impact on route choice. Furthermore, visible congestion was identified as a decisive factor by Xuan and Kanafani (2014). However, they rejected the conclusion that VMS accident messages have a significant impact on route diversion. Inconclusive results can be found about the influence of the incident cause on route choice (see e.g. Chatterjee et al. 2002; Poulopoulou and Spyropoulou 2015).

Among the most widespread uses of VMS, we can mention route guidance, which consists of suggesting alternative itineraries to drivers with the aim of influencing their route choice (Spyropoulou and Antoniou 2015). Within toll-free environments, route guidance on VMS has demonstrated it can positively influence on diversion rate (see e.g. Abdel-Aty and Abdalla 2004; Jeihani et al. 2017; Poulopoulou and Spyropoulou

2015). The effectiveness of route guidance may increase according to different factors. For instance, Yan and Wu (2014) concluded that graphic information within the message improves VMS effectiveness compared to text-only messages. Additionally, familiarity and previous knowledge of the road network have also been shown to play an important role in route choice (see e.g. Ben-Elia and Shiftan 2010; Knorr et al. 2014; Ma et al. 2014).

ATIS and real-time information have been shown to be more effective and valuable in non-recurrent congestion and unexpected incidents (Ben-Elia et al. 2008). Tsirimpa et al. (2007) found that unexpected congestion fosters travel patterns changes in response to ATIS information. Regarding other trip factors, Emmerink et al. (1996) concluded that flexible arrival times reduce the likelihood of route diversion. The distance of a trip is also a contributory factor for route diversion, in the sense that the longer the distance of the trip, the more likely the driver diverts (Abdel-Aty et al. 1997; Li et al. 2015). By contrast, results concerning the influence of drivers' socioeconomic characteristics on route choice are inconclusive, as can be extracted from the contributions by, among others, Feng and Kuo (2007), Tsirimpa et al. (2007), Gan and Ye (2012) or Jeihani et al. (2017).

While previous research has mainly focused on the performance of VMS in toll-free environments, few contributions have analysed its performance on route choice when a tolled alternative is available. Knorr et al. (2014) explored route diversion between a free and a tolled highway after pre-trip information has been supplied, and concluded that the provision of identical information to all road users does not benefit them in a significant way. By conducting a stated preference survey in Texas, Zhang et al. (2014) found that toll road usage might be favoured by the provision of both pre-trip and en-route information. They also determined that drivers taking VMS as their primary mode of receiving traffic information are more likely to divert to toll roads. Furthermore, frequent commuting trips or rescheduling activities due to information displayed decrease the drivers' satisfaction with the information provided, as pointed out by Al-Deek et al. (2012). The literature on explanatory factors that can influence route choice with a tolled alternative, apart from the information provided to the driver, is broad. The reader is referred to e.g. Al-Deek et al. (2009) or Cantos-Sánchez et al. (2011).

Three main techniques have been used in the scientific literature for analysing the impact of information provided to the user on en-route diversion: stated preference (SP) and revealed preference (RP) questionnaires; traffic, travel, or driving simulations; and traffic counts. The studies based on SP surveys and driving simulators are more numerous (Xuan and Kanafani 2014) because they can incorporate both driver and trip characteristics, as well as obtain the individual perceptions and attitudes towards VMS. Nevertheless, it has been generally acknowledged that these techniques may not reflect the actual behaviour of travellers since responses are generally overestimated, because of the lack of commitment of participants (Xuan and Kanafani 2014) compared to RP surveys and loop detector data. This trend has been observed in many case studies previously conducted in, for example, London (Chatterjee et al. 2002), Shanghai (Xu et al. 2011), and the United Arab Emirates (Ahmed et al. 2016). With the aim of taking a more realistic approach, some studies combine SP questionnaires with RP data (see e.g. Choocharukul 2008; Kusakabe et al. 2012). Alternatively, other authors use field data such as loop detector data since they reflect the actual drivers' behaviour (Foo and Abdulhai 2006; Schroeder and Demetsky 2011; Xuan and Kanafani 2014).

As can be seen, the influence of VMS on route diversion, including a toll-road alternative, has been scarcely analysed up to date, particularly concerning toll roads within metropolitan areas. Therefore, there is a need to conduct further research in this field, given its potential usefulness in reducing traffic congestion and in making a more efficient use of road infrastructure by using the excess capacity supplied by the tolled alternative.

Case study and data collection

This section presents the case study chosen to analyse the impact that en-route information provided to road users through VMS had in their route choice, focusing on the role played by VMS. Next, we describe the case study explored, which comprises two fairly parallel roads giving access to the city of Madrid (Spain). Secondly, we explain the variables and data series collected for this research.

As noted above, the paper focuses on the impact of the information provided to drivers through variable message signs (VMS). Despite the fact that many other channels are available nowadays that supply en-route information (e.g. mobile apps, GPS navigators, radio, etc.), VMS have some positives aspects for such analysis. Firstly, it is currently—at least, in the case of Spain—the main channel used by the National Traffic Authority (DGT) to provide en-route information to drivers. Furthermore, this channel guarantees that the information definitely reaches all the drivers, regardless of whether they have a navigator (whether pre-installed in the vehicle or acquired later by the individual) or used any mobile app during the trip. Additionally, en-route information shown in VMS in Spain—covering, for example, incidents, travel time within the road network, etc.—is generally more trustworthy for the user (as shown by Zhang et al. 2014) and often more detailed than those disseminated through alternative channels.

Description of the case study: the Madrid A3-R3 corridor

With a total of 17,021 km, Spain has the longest high capacity road network yet built within Europe. The current national toll network mainly comprises purely interurban toll roads, with some few sections located in metropolitan areas such as Madrid or Barcelona. The highway network within the Madrid metropolitan region was mainly built during the 1980s and early 1990s, when the government designed a fully publicly-funded program to connect Madrid, geographically located in the centre of the peninsula, with radial high capacity connections up to the most important Spanish cities. Then, six main free highways (named A1–A6) were built to easily connect Madrid, in a fairly homogeneous way, with the rest of the regions. A3 is one of these main highways, connecting Madrid to Valencia and Eastern Spain.

Since the mid-1990s, the liberal position of the elected Popular Party and the need to contain the public deficit as a prerequisite for joining the Eurozone moved the central government towards using the toll concession approach to build new high capacity roads. Toll highways granted in this period focused on reducing the increasing road congestion within the metropolitan area of Madrid. To that end, the central government promoted four toll roads (named R2–R5, with a total of 240 km) parallel to four of the existing free radial highways (A2–A5, respectively) entering the city of Madrid, starting their operation between 2003 and 2004. The impact of the economic crisis in Spain reduced the actual traffic levels compared to the expected ones, in both the tolled and free roads, and these levels have not started to recover until the last few years. Further details regarding the performance of toll expressways in Madrid can be found in Vassallo et al. (2012).

We have chosen to analyse, as our case study, the impact that the information provided through VMS has on drivers' route choice on the A3–R3 corridor. This corridor comprises two of the main roads (see Fig. 1) mentioned above: (1) the A3 highway, a free long-distance high capacity road connecting Madrid and Eastern Spain; and (2) the R3 expressway, a 33 km-long toll road running parallel to A3 as it approaches the city of Madrid. This toll road connects residential areas in the southeastern metropolitan area of Madrid with the city centre. The two roads are fairly parallel but poorly connected to each other, so they are clear competitors. The free highway (A3) attracts most of the traffic within the corridor, with an annual average daily traffic (AADT) around 91,700 veh./day in the area under analysis as of 2016, while average traffic in the R3 expressway is much lower (around 10,900 veh./day). Both roads have the same starting point and very close ending points within the M30 ring road surrounding Madrid's city centre. This fact enables us to isolate the effect of multiple-origin-multiple-destination issues from the research, given that both roads cover the same itinerary.

This corridor—specifically the free highway A3—experiences recurrent problems of congestion, particularly during peak hours (morning/evening) on weekdays due to the high presence of commuting trips. Furthermore, Sunday late evening is also a period with heavy traffic because of the return of weekend leisure trips. Toll road R3 allows drivers to save travel time due to its lower volume of traffic and its higher quality standards. By contrast, congestion problems in the corridor are uncommon in off-peak hours and consequently, travel times along the A3 and R3 are fairly similar in that period. For this reason, the toll operator applies different toll rates on peak/off-peak hours. Toll rates for light vehicles in off-peak hours are 0.112 €/km and around 10% higher in peak hours (see more details below).

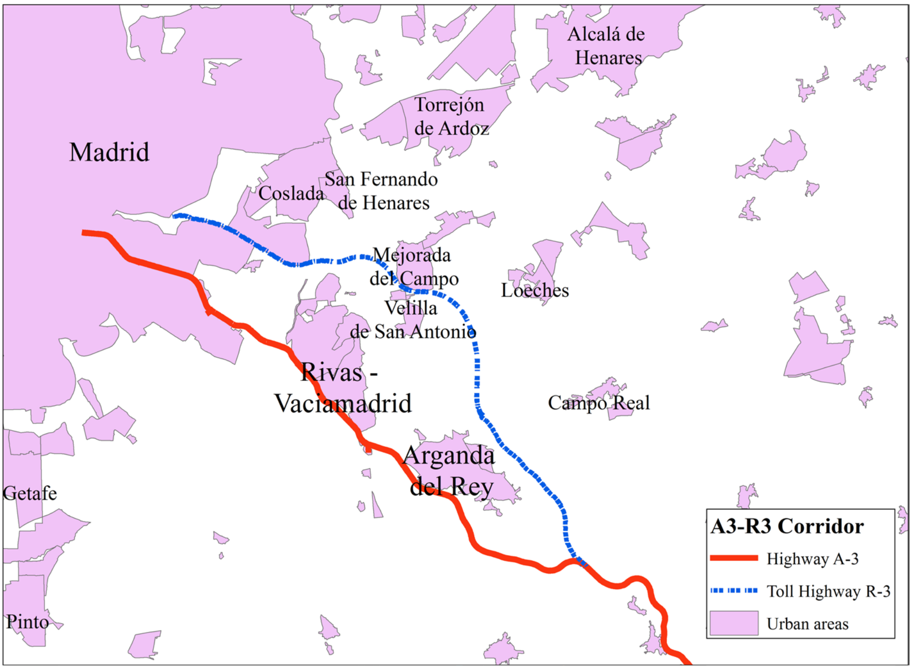

Fig. 1 R-3 toll highway and A-3 highway in the vicinity of Madrid

The en-route information provided to drivers in this corridor is similar to other sections of the high capacity network in Spain. Variable message signs (VMS) are the main means used by the Spanish traffic authority (dirección general de tráfico, DGT) to provide information to road users. The information through VMS includes a wide variety of aspects concerning: speed limits, travel time to specific destinations, congestion, incidents (road works, accidents), general road safety recommendations, etc. Other channels available, such as updated information on DGT webpage, radio transmission, social media, or mobile apps (Comobity) are significantly less used by drivers or still remain at an early stage of implementation.

The A3–R3 case study is of special interest for several reasons. First, it includes two purely competing roads within a fairly congested metropolitan area, as it is the case of Madrid. Second, the alternatives available are a free and a tolled highway, so route choice concerns not only travel time savings but also the payment of a toll. Finally, as detailed below, a VMS panel is located just before the diversion point between A3 and R3. Therefore, whether the information provided to drivers through VMS has a real impact on their route choices can be easily analysed.

Data description

In order to explore the potential impact of the information provided through VMS to road users on their route choice between free and toll roads, we develop a grouped logit (glogit) methodology based on data obtained from the A3–R3 case study. The research focuses on the traffic flow towards Madrid city, given the higher magnitude of congestion problems occurring in this direction in the morning peak hours. Furthermore, the particular location of VMS devices within the corridor (see more details below) makes it possible to inform users about route choice when entering Madrid, but not in the opposite direction.

The research initially made use of loop detector data collected from January 2015 to December 2016. However, the information on traffic volume needed for the analysis was not available for the whole period and consequently, we had to reduce the period to be studied. Basically, loop detectors installed within the A3 highway to collect traffic data experienced repeated operational problems—what is apparently common, at least in some sections of the Spanish highway network—and thus provided missing or inconsistent information on traffic volume for certain periods of time. Consequently, we had to reduce the period studied in the analysis to a seven-month period (January 2015–May 2015; November 2016–December 2016). Data were collected at 15-min intervals, since this is the most disaggregated level to be reached at the same time by all the variables included in the research. This level can be considered sufficiently detailed for analysing many of the factors influencing road diversion, particularly road congestion within the corridor.

The dependent variable to be modelled is road diversion between free and toll roads, particularly the share of traffic diverted to R3 once drivers have the option to choose between taking the toll road or continuing through the free road, within km 33 + 800 (see Fig. 2). The percentage of traffic diverted can be easily calculated, since the Ministry of Transport and the Traffic Authority provide detailed 15-min traffic data from loop vehicle detectors installed in the A3 highway just before and just after the road diversion point (see Fig. 2). Loop detectors used for this research are located in km 34 + 100 and 28 + 500, respectively. The data obtained has been double-checked since traffic data in the toll road are also collected from a loop vehicle detector located just after the road diversion. Specifically, the detector is placed in km 27 + 940 in the R3 expressway, and data are available on

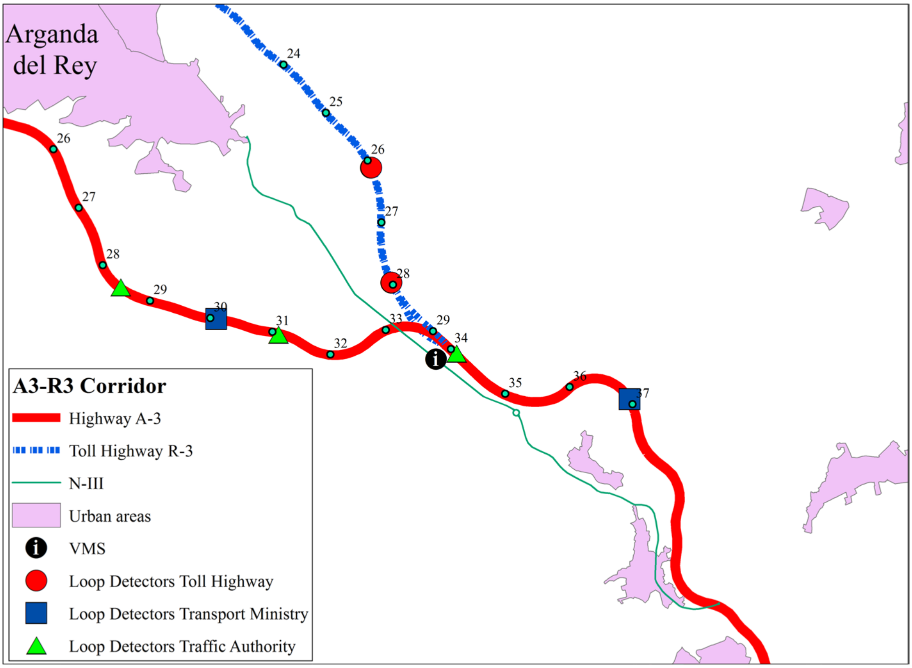

Fig. 2 Location of loop detectors around the diverging point

an hourly basis. Traffic data collected in this research show that, for the period analysed, on average only around 13.3% of traffic in the corridor was diverted to the tolled alternative. Nevertheless, traffic volumes in the two alternatives, and consequently diversion rates, greatly vary depending on both the day of the week and the time of day.

Based on the traffic data collected and the characteristics of the corridor, it can be seen that the research mainly analyses route choice for long-distance trips. The diversion point is located about 35 km away from Madrid city centre, far outside the Madrid metropolitan area. Before the detour point, the A3 highway runs through a scarcely populated area. At this point, the route choice between the free and the tolled highway corresponds to long-distance trips. N-III is the only road intersecting A3 in the area of interest, but it is a two-lane road that mainly serves local traffic and has a very low level of demand (around 3500 veh./day). Therefore, we can assume that its effect on road diversion is negligible since the research mainly covers long-distance movements.

Road diversion is analysed through grouped data from loop detectors that record the evolution of traffic flow within the two high capacity roads available to reach Madrid city centre. This approach has been previously used to analyse the influence of VMS information on route choice (Foo and Abdulhai 2006; Schroeder and Demetsky 2011; Xuan and Kanafani 2014). It has important advantages, such as providing real behaviour from users regarding route choices. Additionally, this approach allows us to avoid some problems found in the literature regarding traditional techniques, such as overestimating diversion rate compared to real data (Ahmed et al. 2016; Yim and Ygnace 1996). The slim connection that exists between users' expressed attitudes (generally extracted from preference surveys) and their real behaviour is particularly critical in the field of toll-setting, as shown by Burris et al. (2012) or Fifer et al. (2014), since route choice in this case also involves the payment of a toll. Furthermore, real data make it possible to analyse road diversion over a long period of time, thus comprising a wide variety of scenarios in terms of congestion level, incidents, weather conditions, type of information provided to drivers, etc. We are aware that alternative approaches such as surveys could provide further information of interest from road users (information at the individual level, e.g., level of income, total trip distance, etc.). This information would be clearly useful to provide further explanatory power to the research. Nevertheless, in order to properly explore and quantify the amount of traffic diverted over time, it would be necessary to collect this information for all individuals driving by this corridor during the whole time span of the research, which is difficult to be done in practice.

Three kinds of explanatory variables have been considered in the analysis to explain road diversion: road supply conditions, information provided to the users, and variables referring to the environment, basically weather conditions.

The first group of variables takes into account different aspects related to road supply conditions that could influence drivers' choices, namely travel time and toll rate. The variable *Travel Time* considers the time (measured in seconds) spent by road users who drive, within the A3 highway, from the diversion section (km 33 + 800) to a controlled point (km 7 + 700) getting to Madrid. Travel time is measured once per minute by intelligent license plate recognition (ILPR) devices installed by the Spanish Traffic Authority along the A3 highway. This variable can be considered a good proxy for traffic conditions and congestion in the free highway. In order to approach the potential non-linear effect of travel time on route choice (what may be linked to the level of service experienced by drivers), we have included powers of travel time as explanatory variables in the model. Travel time is not measured in the R3, but we can assume free-flow conditions on this road given its relatively low traffic volume.

Furthermore, the variable *Day of Week* controls for recurrent distributions of traffic flow coming from the type of day of the week: e.g., weekdays usually present higher traffic volumes during the morning, while Sundays show heavy traffic in late evenings. Additionally, the variable *Toll* takes into account the toll amounts applied on the R3 expressway, comprising periods of peak/off-peak hours in terms of the charges to drivers. Toll rates in peak hours are around 10% higher compared to off-peak periods. Going in the direction of Madrid, peak hours comprise 07:00–11:00 h on weekdays (Monday to Friday), 17:00–19:00 h from Monday to Thursday, 14:00–16:00 h on Fridays, and 15:00–21:00 on some Sundays and bank holidays. These periods with higher tolls are set by the concessionaire with the aim of maximising toll revenues.

The second group of variables of this research includes the information provided to road users by the Spanish Traffic Authority (DGT) through VMS devices installed along the road. Particularly, we focus on the information shown by a VMS panel installed in the A3 highway in km 34 + 100, just before the diversion point (km 33 + 800). This specific VMS panel provides users with updated information from DGT just before they are presented with the choice between the free or the tolled route to enter Madrid. The distance between the VMS and the diverging point is sufficient to choose either route, according to Yan and Wu (2014). The research makes the reasonable assumption that, in an interurban environment with scarcity of other signalling elements in the surrounding area, the messages are easily noticed by all drivers, who also have sufficient time to process the information and choose their route accordingly.

The data collected for this research from the Traffic Authority detail the message shown in the panel, as well as its starting and ending time (with precision in minutes). As mentioned before, many messages are provided through VMS, so a broad categorization has been adopted as pointed out in Table 1. A first group of messages informs drivers about updated travel times spent by previous drivers to cover specific itineraries. In this case, the information offers travel time (expressed in minutes) spent to drive from the detour point (km 33 + 800) to the entrance of Madrid (km 7 + 700) by the A3 highway, as a way to inform about the level of congestion experienced in the free alternative. Additionally, the VMS device informs drivers about any type of incident in the road network: accidents (often providing specific details), road works, traffic jams, etc. Sometimes, both types of information are shown together, so the panel informs drivers about the incidents that happened on the road together with the estimated travel time to reach Madrid city centre. Lastly, the Traffic Authority provides more general information on such different issues as: (1) maximum speed limit permitted; (2) weather conditions: heavy rain, glare, ice, fog, etc.; (3) general recommendations to drivers, as campaigns to promote the use of seat belts, to avoid the consumption of alcohol before driving, etc. It is worth noticing that there are many periods in which no messages are provided to drivers through VMS panels, therefore it is possible to explore the influence of such information on en-route diversion, comparing to a "no information provided" scenario.

As pointed out above, given the great variety of the information shown, the messages have been categorized according to their typology (see Table 1). To properly analyse the information shown regarding travel time measured by the A3 highway (which is provided with accuracy of minutes), this variable has been also categorized. Based on the distribution of travel time observed during the period of analysis, we have considered three categories: values below mean of travel time plus one standard deviation (< 18 min), corresponding to uncongested traffic flow conditions; values between mean average travel time plus one and four standard deviations (18–25 min), corresponding to fairly congested traffic flow conditions; and travel time over this value (above 25 min).

Finally, the analysis incorporates weather conditions since they could influence drivers' choices. At this point, bad weather conditions (heavy rain, fog, etc.) generally lead to speed reductions and heavy traffic, also making driving more unsafe. Then, in these conditions, we may expect that a higher proportion of users would choose the tolled route both for saving travel time and also for safety reasons. We only consider rain precipitation within the category of weather variables since it is the only meteorological phenomenon that occurs with sufficient frequency in Madrid. Weather data were obtained from the State Meteorological Agency (AEMET), Ministry of Agriculture, Food, and Environment, on a 15-min-interval basis. With the aim to reflect more accurately the influence of rain conditions on driving, data were subsequently grouped in three main categories: not noticeable rain (precipitation below 0.1 mm per 15 min), light rain (precipitation over 0.1 mm per 15 min) and moderate rain (precipitation above 0.35 mm per 15 min). It should be noted that no episodes of heavy rain were present in the period under analysis.

A summary of the explanatory variables used in the research is presented in Table 2. Prior to running the modelling, different tests for checking multicollinearity among the explanatory variables were conducted. Given the categorical nature of some explanatory variables, multicollinearity was analysed with the generalised variance inflation factor (GVIF) following Fox and Monette (1992), without significant collinearity effects in our case.

Figure 3 shows the distribution of route choice of all 15-min intervals used within the period under analysis according to the type of message shown and the level of service experienced by drivers. Levels of service have been obtained by categorizing travel time information, following the official scale applied by the Spanish Traffic Authority (see

Table 1 Information provided to road users through variable message signs

Type of information	Message shown	Description
Diversion-related information		
Travel time	Up to M-40: XX min	The VMS provides updated information about the time spent by previous drivers to reach Madrid city centre (intersection with M-40 ring) when using the A3 highway
Incidents	In km XX: accident	The VMS informs drivers that an accident happened in km XX
	Congestion: km XX to YY	The VMS informs drivers about road congestion observed between kms XX and YY in the A3 highway
	Road works: km XX to YY	The VMS informs drivers that road works are being carried out between kms XX and YY in the A3 highway
	Road cut in km XX; leave in exit YY	The VMS informs drivers that the road is cut from km XX onwards and leaving A3 is mandatory in exit number YY
	Lane cut: km XX onwards	The VMS informs drivers that one of the lanes is cut from km XX onwards
	Incident: km XX	The VMS informs drivers that an incident happened in km XX. Detailed information about the type of incident is generally provided: vehicle broken down, etc.
Travel time + incidents	Congestion: km XX to YY; Up to M-40: ZZ min	The VMS informs drivers about road congestion observed between kms XX and YY in the A3 highway, together with the travel time spent to reach Madrid city centre (intersection with M-40)
	Accident: km XX; up to M-40: YY min	The VMS informs drivers that an accident happened in km XX, and the travel time spent to reach Madrid city centre (intersection with M-40)
	Road works: km XX to YY; Up to M-40: ZZ min	The VMS informs drivers that road works are carried between kms XX and YY in the A3 highway, and the travel time spent to reach Madrid city centre (intersection with M-40)
	Slow down under rainy conditions	The VMS advises reducing vehicle speed under bad weather conditions
	Speed controlled by radar. Up to M-40: XX min	The VMS informs drivers about ongoing speed controls, and the travel time spent to reach Madrid city centre (intersection with M-40)
	Slow down	The VMS recommends reducing vehicle speed
Non-diversion-related information		
Speed limits	Remind: speed limit XX	The VMS reminds drivers about the speed limit on the road

Table 1 (continued)

Type of information	Message shown	Description
Weather conditions	Caution: heavy fog	The VMS recommends driving carefully due to weather conditions
	Caution: heavy rain	The VMS recommends driving carefully due to weather conditions
Safety and health campaigns	Do not drink and drive	The VMS reminds drivers not drinking alcohol before driving
	Keep drugs away	The VMS reminds drivers not consuming drugs
	Use seat belt	The VMS reminds drivers that using the seat belt is mandatory
	Control of speed limits	The VMS informs drivers about a campaign in operation to control drivers' compliance with the speed limit
	Recommended having a rest after driving 2 h	The VMS recommends taking a rest after driving 2 h at the latest

Table 2 Explanatory variables analysed in the research

Explanatory variables	Typology	Range	15-min observations
Road supply conditions			
Travel time	Continuous	Mean 15.39; median 14.78	10,550
		SD 2.43	
Toll	Continuous	Mean 3.89; median 3.80	10,550
		SD 0.18	
Day of the week	Categorical	Weekday	7075
		Saturday	1703
		Sunday	1772
Information provided			
Information shown in VMS	Nominal	No message (NM)	5601
		Information without travel time (Information)	135
		Information and travel time (IATT)	34
		Only travel time < 18 min (TT < 18 min)	4168
		Only travel time 18–25 min (TT 18–25 min)	593
		Only travel time > 25 min (TT > 25 min)	19
Weather conditions			
Precipitation level	Ordinal	Precipitation < 0.1 mm	10,240
		Precipitation between 0.1 and 0.35 mm	225
		Precipitation > 0.35 mm	85

Table 3). The equivalence with the level of service established by the Highway Capacity Manual (TRB 2016) is also shown.

In these boxplots, there are outliers corresponding to 15-min intervals with low traffic volume, generally in nocturnal periods. According to the figure, there seems to be a relationship between the diversion rate and the level of service experienced in the corridor. Particularly, the worse the level of service in the free highway A3, the higher the diversion rate to the tolled alternative. We also observe different driver behaviour depending on the type of information displayed. This is the case of, for example, providing information on incidents along with travel time in the free highway, as well as informing drivers about travel times noticeably above usual values experiences on the A3. These preliminary findings need to be confirmed in a more rigorous analysis by using econometric techniques.

Methodology

In order to explore the influence of VMS information on route choice, we adopt a binary logit specification. Logit models are widely applied in the field of transport research, particularly to analyse route choice (see e.g. Al-Deek et al. 2009; Jeihani et al. 2017; Li et al. 2015). A detailed description of this well-known econometric technique is beyond the scope of this paper, so the reader is referred to Ben-Akiva (1985) or Ortúzar and Willumsen (2011), among others. The original formulation of logit models is derived from the utility maximizing behaviour, assuming that decision makers are utility maximizers. Then, according to the economic

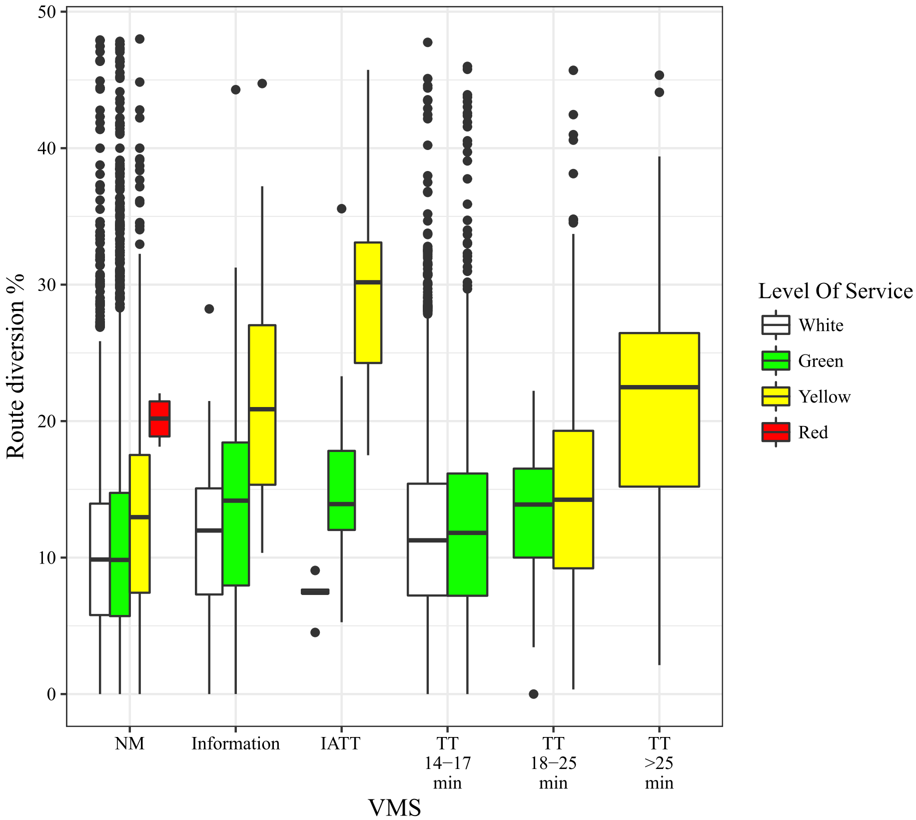

Fig. 3 Distribution of 15-min intervals used in the analysis

Table 3 Equivalence of level of services established by the Spanish Traffic Authority and the Highway Capacity Manual

Level of service (Spanish Traffic Authority)	Level of service (High Capacity Manual)
White	A
Green	B–C
Yellow	D
Red	E
Black	F

theory, the individuals will choose the option (route) with the highest utility, each one determined by a number of explanatory parameters.

As explained by Ben-Akiva (1985), the probability that individuals will choose a certain alternative can be expressed as shown in Eq. (1), where $P(Y=1)$ equals the probability that the individuals with characteristic X_n choose the non-reference category of the dependent variable:

$$P(Y = 1) = \frac{e^{V_{nj}}}{1 + e^{V_{nj}}} = \frac{e^{\beta_j X_{nj}}}{1 + e^{\beta_j X_{nj}}} \quad (1)$$

In this paper, a binary logit model is developed to analyse whether the information provided through VMS influences drivers' route choice between a toll road (R3) and its free parallel alternative (A3). Therefore, the response is treated as a binary variable and, consequently, a binary logit model is applied. The data used in the empirical model are grouped, as mentioned before. For grouped data, the dependent variable is the observed proportion of success, which means the share of cars that divert to the toll road (R3).

The logistic regression model using grouped data can be specified as:

$$L_i = \ln \frac{P_i}{1 - P_i} = \alpha + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_k X_k \tag{2}$$

where P is the share of traffic diverted to the toll road (R3 expressway), X_i is a vector of explanatory variables, and β_i is a vector of coefficients to be estimated. Modelling results and coefficients can be interpreted as in traditional binary logit models.

Modelling results and discussion

This section summarizes the main results from the analysis conducted in this research. The data collected above have been used to develop a binary logit analysis to explain route choice between the free highway A3 and its competing tolled alternative (R3).

Three explanatory variables used in the model are categorical (*Day of the week*, *Information shown in VMS* and *Precipitation*), so choosing a base case as a reference is needed to properly interpret modelling results. This enables us to determine whether the route choice of drivers under certain conditions is statistically significant when compared to the base case. Regarding the day of the week, weekdays are selected as the base case, since they represent the most common situation. No information in the panel is taken as the base case for this model, with the aim to capture the influence of the different types of messages on drivers' behaviour. Additionally, non-diversion-related information is considered in the models as no information, due to the lack of influence on route choice. Finally, we decided to include interaction terms between the type of day and type of information provided to the user, in order to explore whether the information shown in VMS has a different influence on route choice depending on the day of the week. This may seem reasonable given the differences in traffic conditions and type of users characterising each type of day. For instance, weekdays typically cover commuting trips made by frequent users of the corridor, while Sundays generally correspond to weekend leisure trips made by occasional drivers. It is worth noticing that, due to the lack or scarcity of observations for some categories analysed, we could not obtain estimates for some interaction terms (e.g. Saturday and Sunday interactions with *IATT* within the *information shown in VMS* variable).

The signs of the modelling coefficients (see Table 4) and their statistical and practical significance are, in general, in line with the expected results. The model estimates confirm that, from a statistical point of view (p value < 0.05), drivers' route choice is influenced by road condition supply as well as by the VMS information provided by traffic authorities.

First of all, road diversion significantly changes depending on the day of the week, as can be concluded from the modelling results. Compared to the base case (weekdays), the odds of choosing the toll road decreases by 4.3% on Saturdays and increases by 25.2% on Sundays. The positive result on Sundays could be related to the higher proportion of weekend leisure trips generally observed on this day of the week. Given the low frequency of this type of trips, drivers would be more willing to pay for avoiding congestion problems

Table 4 Modelling results: route diversion to the R3 expressway

Variables	Logit model		
	Coeff.	Std. error	*P*-value
Day of the week (reference: Weekday)			
Saturday	−0.044	0.009	0.000
Sunday	0.225	0.007	0.000
Travel Time	0.136	0.007	0.000
Travel Time^2	−0.003	0.000	0.000
Travel Time^3	0.000	0.000	0.000
Toll rate	−0.097	0.011	0.000
Information shown in VMS (reference: no message)			
Information	0.214	0.021	0.000
Saturday × Information	0.484	0.042	0.000
Sunday × Information	−0.133	0.036	0.000
IATT	0.602	0.022	0.000
TT < 18 min	0.144	0.006	0.000
Saturday × TT < 18 min	−0.009	0.012	0.466
Sunday × TT < 18 min	0.040	0.010	0.000
TT 18–25 min	0.104	0.010	0.000
Saturday × TT 18–25 min	−0.150	0.066	0.023
Sunday × TT 18–25 min	0.297	0.015	0.000
TT > 25 min	0.543	0.029	0.000
Saturday × TT > 25 min	–	–	–
Sunday × TT > 25 min	−0.301	0.048	0.000
Precipitation level (reference: P < 0.1 mm)			
P 0.1–0.35 mm	−0.107	0.013	0.000
P > 0.35 mm	−0.131	0.023	0.000
Intercept	−3.190	0.072	0.000
Initial log-likelihood	−87572.70		
Final log-likelihood	−80827.37		
Pseudo R^2 Mc Fadden	0.077		
Pseudo R^2 Nagelkerke	0.078		
Number of observations (15-min intervals)	10,550		

and saving travel time when returning from this type of journeys. By contrast, diversion rates on Saturdays are significantly lower compared to weekdays, probably due to the scarcity of congestion problems generally observed this day of the week, which makes the free A3 highway more competitive.

As seems reasonable, traffic congestion experienced in the free alternative (A3) seems to play a major role when explaining the choice of the tolled alternative, since the variables controlling for travel time (*Travel Time, Travel Time^2, Travel Time^3*) were found statistically significant. These modelling coefficients have the expected sign. *Travel Time* has a positive coefficient, indicating that the higher the travel time to get to Madrid using the free highway the more likely the drivers would divert to the tolled R3 expressway. Moreover, as expected, the quadratic term of travel time (*Travel Time^2*) is also statistically significant and negative. This indicates the non-linear effect of travel time—that is, congestion level—on route diversion. Additionally, the coefficient for *Travel Time*[3] is positive and statistically significant, with a magnitude very close to zero. As a result, rate diversion is constantly increasing, but the resulting slope starts to decrease (despite keeping positive) for travel times higher than 24 min. Over 30 min, the diversion rate remains approximately constant. The coefficients obtained in the model let us calculate travel time elasticities, which vary depending on the traffic flow conditions (that is, travel time in the A3) given the nonlinear effect considered in the research. Then, for TT = 15 min (average value in the corridor), we obtain a travel time elasticity of the tolled route share of 0.79, while the value for the untolled route share is − 0.12. Similarly, for TT = 25 min (fairly congested conditions in the corridor), the travel time elasticity of the tolled route share decreases to 0.56, and the elasticity for the untolled route share goes also down to − 0.09. As can be observed, elasticities are lower in those situations when the free highway A3 is less competitive in terms of travel time, compared to the tolled route R3.

Concerning the influence of toll prices applied to the charged alternative, we obtain a negative statistically significant coefficient (− 0.097). This result seems reasonable given that the higher the toll, the lower the diversion rate to the charged alternative. This results in a toll elasticity (see Table 5) of the tolled route share of − 0.33, which is in line with other previous research calculating toll elasticities in Spain and the US (see e.g. Gomez et al. 2016; Huang and Burris 2015; Matas et al. 2012). Similarly, for the untolled route share, we obtain a toll elasticity of 0.05. Then, we can observe that road demand in both routes (free and charged ones) are fairly inelastic to toll prices. Given the low diversion rates to the tolled route observed in the corridor, it seems that tolls applied are too high to make the charged route more attractive, and then the road capacity available is not efficiently used. Model coefficients can be also used to calculate value of time (VOT) for road demand, with an average result of 28.4 €/h in our case.

Next, we comment on the results regarding the influence of VMS information on drivers' route choice. Firstly, we can observe that the type of information provided to drivers significantly influences their route choice when one of the alternatives is tolled. Compared to the base case (providing no information in the panels), showing general information about incidents happening in the free highway (accidents, road works, etc.) increases the odds of choosing the tolled route (23.9%). This seems reasonable given drivers' willingness to pay for avoiding road incidents and consequently reducing travel time to destination. We can also observe that the interaction terms with the *Day of the week* categories are statistically significant, then the effect of providing this type of information is different depending on the type of day. According to the modelling coefficients (0.484 and − 0.133), we can conclude that on saturdays the influence of providing information about road incidents is higher than on weekdays, whereas on Sundays the impact on route choice is lower. Differences may be due to the type of user (frequent/occasional) and trip purpose (commuting/weekend leisure) typically characterising each type of day. More interestingly, adding travel time estimates together with incident information on VMS panels (IATT) significantly increases the odds ratio in favour of the tolled alternative, as can be pointed out from

Table 5 Toll elasticities and value of time calculated for the A3–R3 case study

Parameter	Value obtained
Toll elasticity (tolled route)	− 0.33
Toll elasticity (untolled route)	0.05
Value of time (Eur/h)	28.4

the results (+ 82.6%). Then, we can conclude that providing more detailed information to drivers—that is, adding travel time estimates along with incident information—encourages road diversion and makes possible a more efficient use of the existing road infrastructure, particularly those roads with excess capacity. Given the scarce variability of the IATT category within the sample, we could not explore the influence of this type of information depending on the type of day.

Providing drivers with information about travel time also influences their route choice. Even when travel time experienced in the free highway is near average values in its itinerary (< 18 min), providing travel time information increases the odds of the tolled alternative (+ 15.5%), compared to the base case (showing no VMS information). There is hardly any difference between showing travel time estimates of the first interval (< 18 min) and the second interval (18–25 min). According to the modelling results, when traffic authorities inform drivers that travel times are above average values (18–25 min), the odds in favour of the tolled route increases by 11.0% on weekdays, given its ability to reduce travel time. Road diversion to the tolled infrastructure significantly increases when the free highway gets congested, since providing travel time estimates far above average values in the corridor (above 25 min) greatly increases the odds of choosing the R3 expressway on weekdays by 72.1%. These results are clearly in line with Abdel-Aty et al. (1997) and Gan and Ye (2012) regarding the influence of VMS on route choice when drivers are provided with travel time information.

We can also notice that the influence of providing travel time information on route choice changes depending on the type of day, particularly on Sundays. According to the results for interaction terms included in the model, on Saturdays, the influence of this type of information is not statistically different from weekdays when travel time is near average values (< 18 min), while for the second interval (18–25 min) there seems to be no net effect on route choice. All these results are reasonable given the lower vehicle demand generally experienced on Saturdays, which clearly discourages users from diverting to the tolled route. By contrast, for Sundays, the three interaction terms are statistically significant, which indicates a net positive effect of travel time information on toll road choice in this day of the week. Compared to a scenario of not providing travel time information on Sundays, the odds in favour of choosing the toll road increases by 20.2, 49.3 and 27.4% for the categories *TT < 18* min, *TT 18–25* min and *TT > 25* min, respectively. The positive interaction terms for the first two categories (0.040 and 0.297) mean that this effect is higher than on weekdays. Conversely, for the *TT > 25* min category, the impact of the travel time estimates is lower than on weekdays as indicated by the negative interaction term (− 0.301). Despite its significant *p*-value, this coefficient is based on a really scarce number of observations (only five 15-min intervals showing travel time estimates over 25 min on Sundays), so this result should be received with care.

Finally, results concerning the rain variable are briefly commented. These estimates are significantly negative, indicating that the diversion rate is lower when the volume of rainfall is heavier, which is counterintuitive. Despite their significant *p*-values, these coefficients are based on a scarce number of observations with appreciable rain (225 15-min intervals with light rain and 85 15 min-intervals with precipitation heavier than 0.35 mm). Additionally, we should remind ourselves that episodes of heavy rain were not present in the period under analysis, so it is not possible to explore drivers' route choices under severe weather conditions. Although other authors previously concluded that weather conditions do not significantly influence route diversion (Abdel-Aty and Abdalla 2004), we considered weather conditions an interesting factor to be included in the analysis in order to net out the influence of the rest of regressors.

Regarding the goodness of fit of the estimated results, we determined a pseudo R^2 McFadden of 0.077 and a pseudo R^2 Nagelkerke of 0.078, which may be considered satisfactory for logit specifications according to Hensher and Bradley (1993). This result is comparable to the fit accuracy achieved in similar studies (see for instance Al-Deek et al. 2009). In addition, a likelihood-ratio (LR) test was adopted to check that the final models are overall significant when compared to the empty model (p-value = 0.000). We should remind that the research exploited grouped data, while using information at the individual level would increase the explanatory power of the model.

Apart from the modelling results, some comments should be made regarding the toll scheme implemented. In the case of the A3–R3 corridor, a pre-scheduled charging scheme—with higher tolls during peak hours—is applied. Nevertheless, demand in the corridor appears to be inelastic—as shown by the low values obtained for the toll elasticities—and diversion rate to the tolled route remains low, which suggests that tolls are too regressive and then do not encourage sufficient diversion to bring the road network to a user equilibrium. As a consequence of that, traffic volumes are not well balanced between the two routes (tolled/untolled), the road capacity of the corridor is not efficiently utilized, and the traffic flow in the corridor is not optimized. From a policy perspective, this is detrimental to welfare so other toll regimes—e.g., dynamic pricing—should be explored. Unfortunately, until now the Spanish concession law has not allowed implementing this type of flexibility in toll concession contracts, which makes toll roads less attractive in cases such as the one explored in this research.

Conclusions and recommendations

This paper conducted a binary logit model to explore the influence of providing en-route information through variable message signs (VMS) on drivers' route choice when both a free and a tolled alternative are available within the same corridor. From the analysis, we obtained some interesting conclusions.

The first conclusion is that displaying relevant information on VMS panels produces significant variations on route diversion, even when one of the alternatives is tolled. Notwithstanding that the alternative route implies an extra cost for the users, their behaviour is shown to be influenced by the type and the content of the messages displayed. This result corroborates that VMS represent a relevant tool to manage road traffic, improve drivers' reliability, and make a more efficient use of road infrastructure, especially to address the imbalanced demand often observed between toll highways and the competing congested free roads.

The second conclusion, strongly connected to the first one, concerns the provision of real-time information to drivers by those stakeholders involved in traffic management. To a large extent, the results of this paper can be generalised to other information sources, such as mobile applications or in-vehicle devices, which have a great potential for widespread use in the near future. Therefore, traffic authorities and operators should incorporate or intensify, within a wider framework of multiple information sources, the use of these new sources for spreading real-time information, given its effectiveness in rerouting vehicles away from congested roads.

From a more operational perspective, the third conclusion is that informing drivers about travel time estimates together with incident messages increases route diversion. Furthermore, we can conclude that providing en-route travel time information is also an effective policy. However, for regular drivers on the same route, informing them about time delays instead of travel time estimates would be a more effective practice. Based on these results, traffic managers should also consider that VMS messages influence drivers differently on weekdays and weekends, which may be related to the different traffic conditions and the type of user (in terms of both trip frequency and trip purpose) characterising mobility during each type of day. From a policy perspective, our results should be of great help in improving the real-time route assignment within toll environments in case of recurrent congestion or unexpected events that cause significant delays.

From the results of this paper, some issues emerge as challenges for further research. Firstly, the investigation should incorporate the influence of drivers' socioeconomic data in the empirical analysis on route diversion to toll roads by, for example, exploring data at the individual level. In addition, it may be interesting to replicate the analysis for regular commuting trips within metropolitan areas, or addressing the influence of other information channels widely extended nowadays, as for example GPS navigators or mobile apps. Finally, further contributions should examine individual choices between free and toll roads, together with alternative means of transport (e.g. public transport) in those cases where they represent a competitive option, such as daily mobility within metropolitan areas.

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Author's contributions FR: Literature search and review, case study design and manuscript writing. JG: Manuscript writing, study conception and content planning. TR: Theoretical development, analytic calculations and model derivation. RJ-P: Acquisition and interpretation of data. JMV: Study conception, content planning and critical revision.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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