Empirical Analysis of Dynamic Route Choice Behavior on German Freeway A8 Based on Large Scale Vehicle Fleet Data

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***Abstract*— With the availability of large scale probe data from connected vehicle fleets it is possible to empirically investigate the route choice behavior of individual vehicles in road networks. In this paper the bypassing of traffic jams on freeways is analyzed for a road network extract south of Munich in Germany. It is shown for this road network extract that the benefit of alternate routes in order to bypass traffic jams on freeways is very limited and almost diminishes depending on the severity of the congestion. Significant travel time savings are only possible with severe traffic jams on the freeway with delays greater than 30 minutes. Furthermore, vehicles on alternate routes have more travel time savings immediately after the emergence of the congestion while vehicles on alternate routes at a later date have less travel time savings or even lose travel time.**

***Keywords* —** dynamic routing, empirical traffic data analysis, floating car data, route choice behavior

I. Introduction

In the past decades several scientists have worked in the field of route guidance including dynamic travel times. In addition to solely static routing, dynamic traffic information and congestion have been taken into account. Papageorgiou [1] presents a model to split traffic flows and a system or user optimum taking feedback for dynamic traffic conditions into account. Wahle et al. [2] simulate actual travel times supplemented by real measurements and show user optimization in a route guidance system based on multiple criteria. Using traffic simulations, Chen et al. [3] investigate the positive effect of path-based travel times in comparison to only link-based travel times. Ben-Akiva et al. [4] present a dynamic traffic assignment model intended for central-based real-time predictive route guidance: travelers would receive route guidance information from the center including traffic predictions. In a similar direction, Mahmassani [5] investigates the optimization of a central controller for the provision of real-time routing information: the ideal case would be the knowledge of all time-dependent origin-destination flows over the whole planning horizon in the network. More recently, Matschke [6] simulates different effects of dynamic information in the travel times in road networks. Li et al. [7] model the route choice behavior of drivers in urban networks with a Bayesian network and validated their model with a taxi fleet in Bejing. Iida et al. [8] and Selten et al. [9] conducted experiments and simulations on the route choice behavior of drivers in an abstracted road network with one main and one alternate route. Ramming [10], Prato [11] and Frejinger [12] applied several route choice models on route data collected by questionnaires.

All references have in common that they have often used simulation approaches or low scaled stated preference data to support their assumptions because in the past real empirical data including real driver decisions on their routes under real-world conditions have not been available: due to the improved connectivity of more and more vehicle fleets recently, for the first time data from used customer routes in the case of congestions can be investigated in more detail.

Revealed preference data from electronic toll collection systems for analysis of route choice behavior have been used by Tiratanapakhom [13], while Schlaich [14] used mobile phone trajectories.

This paper reveals for a larger group of connected vehicles the dynamic routing behavior for alternate routes under congested freeway conditions. We try to answer the following questions:

1) Under which conditions and which severity of a travel time increase on a freeway segments users have used alternate routes?
2) What is the proportion of users taking alternate routes in comparison to those staying on the freeway in a congested situation?
3) How many users have a travel time advantage using the alternate route?
4) How is the travel time advantage distributed over time, i.e., when and how can a user of the alternate route had and time advantage?
5) Can we understand some general principles in which cases taking the alternate routes make sense for the individual customer?

This contribution tries to investigate these questions based on some illustrative examples from the German road network near Munich.

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II. DATA BASIS

All vehicles of the connected fleet are part of a floating car data (FCD) system of one car manufacturer and therefore transmit trajectory data to a traffic service provider (TSP). There is no information about the vehicles and the drivers available. So it cannot be distinguished between commuters, tourists and other groups. There are also no implications about the network knowledge of the drivers possible.

The TSP aggregates all trajectory data to the current traffic state of the road network and provides in turn all connected vehicles with real time traffic information [15]. All vehicles are equipped with a navigation system and obtain the real time traffic information based on the TMC (Traffic Message Channel) location table for Germany. That implies, that traffic information is only available on higher road classes like freeways and arterial roads. For other roads not covered by the location table, no traffic information can be transmitted from the backend to the navigation system. Also it is not guaranteed, that the navigation system is active and provides a dynamic route and guiding to the driver.

The trajectory data contains timestamp, latitude and longitude and is anonymized to remove any mapping between individual vehicles and trajectory data. By a session identifier it is possible to link all parts of one trajectory to a complete trip trajectory. The start and end of a trajectory is not determined by the logical start and end of a trip. Instead the vehicle obtains a new session identifier after a sufficient long bus idle time of the vehicle electronic system. Therefore, a trajectory can consist of several logical trips, if there are only short vehicle stops between these trips.

The FCD system generates million trajectories per day consisting of billions of GNSS (global navigation satellite system) points in Germany. In this paper the time period from 1st October to 19th October 2015 is analyzed. After matching the trajectory data on the road network, empirical travel times and average velocities can be computed for arbitrary road stretches. We focus in our analysis to one part of the German freeway network and its bypassing alternate routes.

III. ANALYZED ROAD NETWORK

The analyzed road network in this paper is located in Germany south of Munich and spanned up by the freeways A8 and A99 (Figure 1). The considered part of the freeway A8 stretches from interchange Brunnthal (Kreuz Brunnthal) to interchange Inntal (Dreieck Inntal). The freeway A99 is connected to the A8 by the interchange Brunnthal. Alternate routes have both start and end on a freeway and bypass at least one road segment of the A8. These alternative routes are either suggested by the navigation system or the driver decides for this alternatives due to his own knowledge of the network and the usual traffic conditions. Only the current position of the vehicle is transmitted to the backend server. Destination and current route to the destination are not transmitted. Therefore, it is not possible to distinguish between routes suggested by the navigation system and selected by the driver.

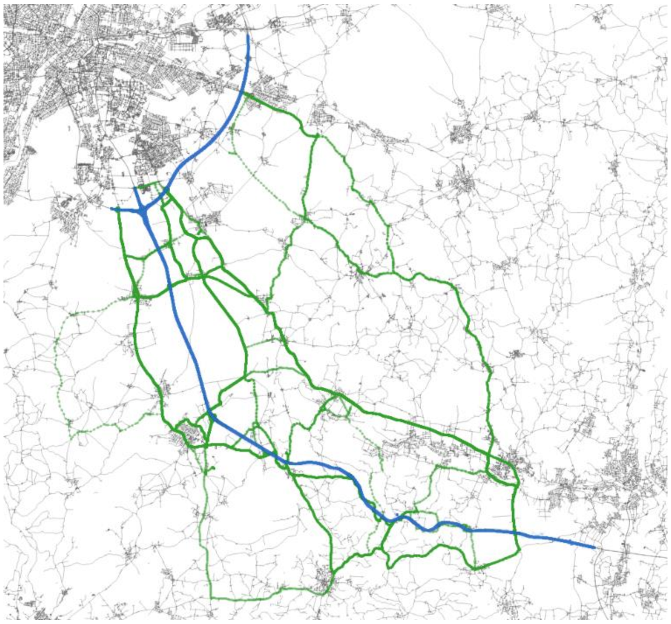

Fig. 1 Trajectories of vehicles on freeway and on alternate routes.

All trajectory parts on the considered freeway and alternate routes are plotted as GNSS points in Fig. 1. The position points on the main route are colored in blue and the points on alternate routes are colored in green. While the main route is prescribed, there are no limitations on the alternate routes. All real driven connections between two interchanges of the specified main route are taken into account. As can be seen there exist several different alternate routes between the interchanges. On road stretches of alternate routes with only one trajectory individual GNSS points can be distinguished, while with more and more trajectories on the road stretch the line intensity increases and individual GNSS points cannot be distinguished anymore. So the line intensity of the alternate route corresponds to the usage frequency of the connected vehicles.

The real road network of Figure 1 can be abstracted to a schematic representation as shown in Figure 2. Again the main routes are colored in blue and the alternate routes in green. In the schematic representation only those alternate routes are taken into account, which are likely to be driven. This depends first on the time difference between alternate route and freeway without any congestion and second on the probability of severe traffic jams on the freeway. Between Bad Aibling and Weyarn severe traffic jams occur often due to accidents and so also alternate routes with usually longer travel times are then attractive and can yield to lower travel times compared to the main route. The interchange Brunnthal is often very congested during rush hour and thus the slightly longer alternatives are also popular.

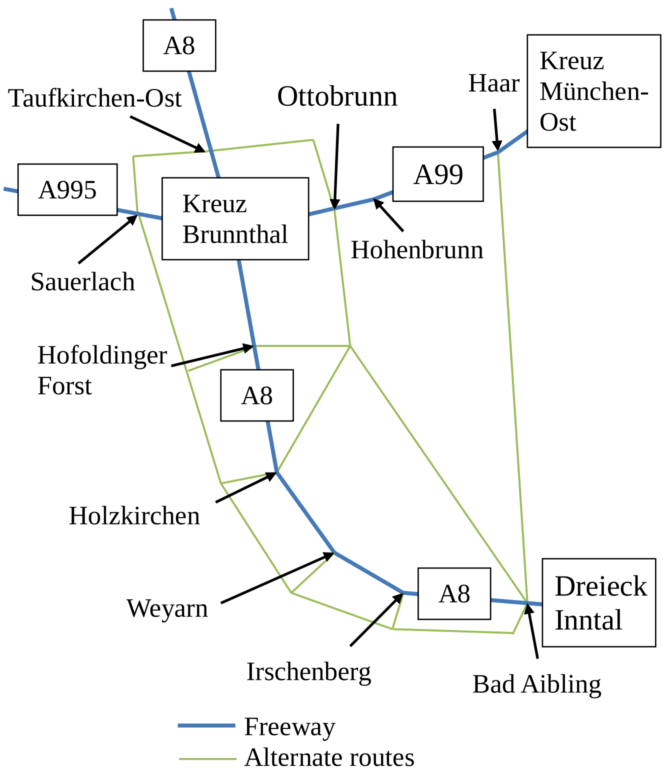

Fig. 2 Schematic representation of the evaluated traffic network: the network consists of the freeway A8 south of Munich and the interchange Brunnthal between A8 and A99.

IV. General Statistics

This part gives an overview over alternate route usage on all days of the evaluated time period and road stretches. First the alternate routes are evaluated in a temporal context in Table I and second in a spatial context in Table II.

TABLE I

TEMPORAL OVERVIEW OF ALTERNATE ROUTE USAGE IN THE EVALUATED TIME PERIOD FROM 2015-10-01 TO 2015-10-19: DAYS WITH LESS THAN 5 ALTERNATE ROUTES ARE NOT TAKEN INTO ACCOUNT.

Freeway direction	Date	Number of vehicles	Travel time savings in [min]	
			Average	Median
North	2015-10-01	42	15.4	7.1
	2015-10-07	10	-4.3	-1.5
	2015-10-08	20	3.2	4.3
	2015-10-09	6	0.4	0.2
South	2015-10-01	54	3.5	2.8
	2015-10-02	48	2.2	1.1
	2015-10-05	28	-2.7	-4.2
	2015-10-06	9	-7.6	-5.2
	2015-10-07	19	1.0	-2.7

The days with considerable alternate route usage are given in Table I, whereas days with less than 5 vehicles on alternate routes are omitted in the table. On the majority of days of the evaluated time period there are less than 5 alternate routes per day with mostly free flow or smaller congestions on the freeway. On the other days listed in Table I with at least 5 alternate routes per day, there exist on average on 6 days travel time savings by alternate routes and on 3 days travel time losses.

As it can be seen, the median travel time deviates significantly from the average travel time in some cases. On the 1st October 2015, the average travel time is more than double as high as the median in direction north. This means, that there are few vehicles which reduce their travel time by 20 minutes and more, but the majority of the vehicles on alternate routes saves only some minutes of travel time or even increase their travel time. On a first look it seems that the number of vehicles correlates to the travel time saving. This would be an expected correlation as the actual travel time saving is up to a certain kind predictable for each driver and with more expected travel time savings more drivers probably will take an alternate route. But on 5th October in direction south 28 vehicles take alternate routes with a median travel time loss of 5 minutes and an average loss of 3 minutes. In this case most of the drivers (or their navigation system) overestimated the travel time saving on the alternate route.

TABLE II

SPATIAL OVERVIEW OF ALTERNATE ROUTE USAGE IN THE EVALUATED TIME PERIOD FROM 2015-10-01 TO 2015-10-19: ALTERNATE ROUTES WITH LESS THAN 5 OCCURRENCES IN THE WHOLE TIME PERIOD ARE NOT TAKEN INTO ACCOUNT.

Route	Number of vehicles	Travel time savings on the alternate route compared to the main route in [min]		
		Average	Median	Without Congestion
A8 Bad Aibling -> A99 Ottobrunn	21	17.4	4.6	-12
A8 Irschenberg -> A8 Weyarn	5	0.7	0.2	-9
A8 Irschenberg -> A8 Holzkirchen	5	34.4	47.4	-15
A8 Weyarn -> A8 Holzkirchen	8	-2.0	-0.8	-8
A8 Holzkirchen -> A99 Ottobrunn	9	3.9	1.9	-10
A8 Hofoldinger Forst -> A99 Ottobrunn	5	-3.5	-2.7	-5
A99 Haar -> A8 Bad Aibling	5	-0.8	-5.3	-14
A99 Ottobrunn -> A8 Hofoldinger Forst	47	1.6	-0.1	-7
A99 Ottobrunn -> A8 Holzkirchen	21	1.6	-0.2	-9
A99 Ottobrunn -> A8 Bad Aibling	13	-8.6	-11.3	-13
A995 Sauerlach -> A8 Hofoldinger Forst	33	3.9	6.0	-7
A995 Sauerlach -> A8 Holzkirchen	24	0.5	2.2	-13

The travel times of alternate routes in Table II are in the range of 5 to 15 minutes higher than the corresponding travel time on the freeway without any congestion. So travel time savings on the alternate routes are only possible if there are delays in the same range on the freeway. Obviously there are significant differences between the same alternate routes in different directions. For the alternate route between Bad Aibling and Ottobrunn on average there are time savings in northern direction and losses in southern direction. The same applies for the alternate route between Ottobrunn and Hofoldinger Forst. A possible reason for this is the different probability of congestion on the freeway in each direction.

In addition to the real driven alternate routes, there exist also officially declared detours (in german: "Bedarfsumleitung") between subsequent interchanges in Germany. Those detours are permanent and marked by blue road signs with the letter "U" followed by a constant number between 1 and 99. The permanent detours are the logical alternate route to the freeway and can be often combined to longer alternate routes. So in general most of the alternate routes coincide with one or more concatenated permanent detours. Only routes between Bad Aibling and Ottobrunn/ Haar as well as in reverse direction are not part of the official permanent detours as several interchanges are skipped.

V. Detailed Analysis of Individual Days

In this part one day for each direction should be analyzed in detail to empirically show phenomena of alternate route usage. The selected day for the direction north is Thursday, 1st October 2015 with a severe traffic jam between Bad Aibling and Holzkirchen (Fig. 3). The number of vehicles of the connected fleet on this road stretch is nearly constant between 12:00h and 18:00h and varies from 17 to 21 vehicles per hour (Fig. 3a). Due to the traffic jam there is a total delay of 80 minutes at 12:00h which decreases below 10 minutes at around 15:30h before rising again to around 30 minutes before totally diminishing at around 18:00h (Fig. 3b). The travel time delays in Fig. 3b are given only for those parts of the freeway, where the maximal delay is greater than 5 minutes on any point of time. Otherwise the delay information of this freeway segment is omitted.

As can be seen between 12:00h and 15:00h in Fig. 3, there is a relation between the number of vehicles on alternate routes and the total delay on the freeway. Also the resulting travel time savings correlate with the delay time on the freeway. However, also some drivers leave the freeway not before Weyarn, when they already passed the major traffic congestion. As they decide too late to leave the freeway and bypass the traffic jam on an alternate route, they do not reduce their travel time any more by detouring. Between 15:00h and 18:00h also some drivers decide to leave the freeway in Weyarn after their travel time increased in traffic jam before. As before, they do not save any travel time on the alternate route. Due to no delay on the freeway, they even lose up to 20 minutes on the alternate routes. The ratio of vehicles on alternate routes to main route obviously depends on the severity of the congestion. On this day up to 64% of the observed fleet drive on the alternate route.

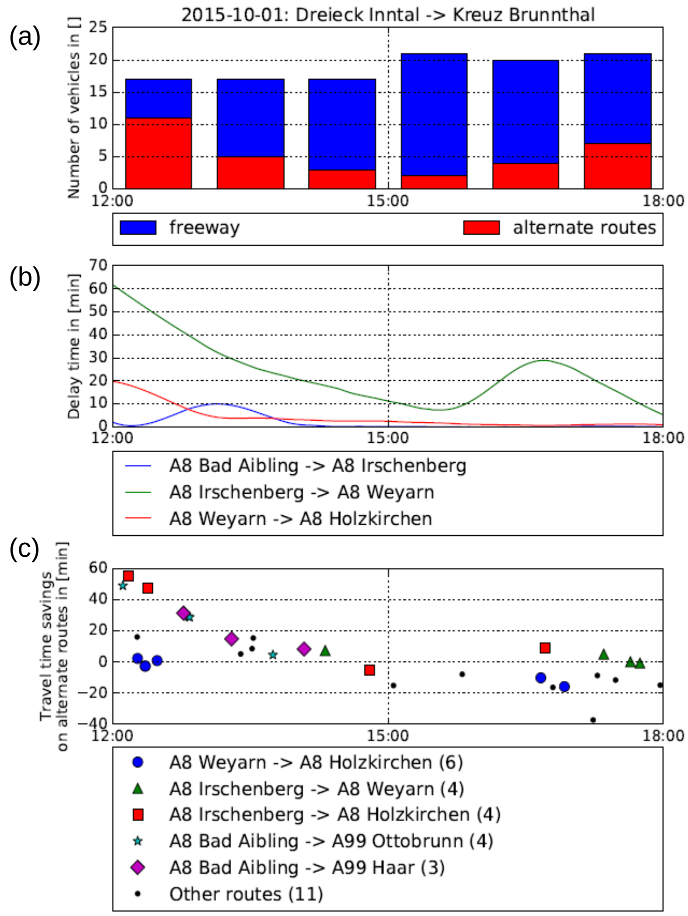

Fig. 3 Traffic jam on the A8 between Bad Aibling and Holzkirchen (direction: north) on 2015-10-01: (a) Number of vehicles per hour on the main route with traffic jam and on alternate routes. (b) Delay time on freeway due to traffic jam. (c) Travel time savings on alternate routes.

For the detailed analysis of the other direction Wednesday, 7th October 2015, is selected (Figure 4). There is one severe traffic jam between Weyarn and Bad Aibling from 13:00h to 16:30h. Additionally, there are two smaller congestions at the interchange Brunnthal between Ottobrunn and Hofoldinger Forst from 7:00h to 10:00h and between Haar and Hohenbrunn from 14:00h to 16:30h. During the congestion at the interchange Brunnthal several vehicles take alternate routes. But on all alternate routes travel time is higher than on the main route, as the congestion affects only vehicles coming from direction Brunnthal. All vehicles from Sauerlach can pass the interchange in southern direction without any travel time delay. There are some possible reasons for this behavior: Either the navigation system suggested erroneously these alternate routes or the drivers decided for the alternate route due to their personal experience.

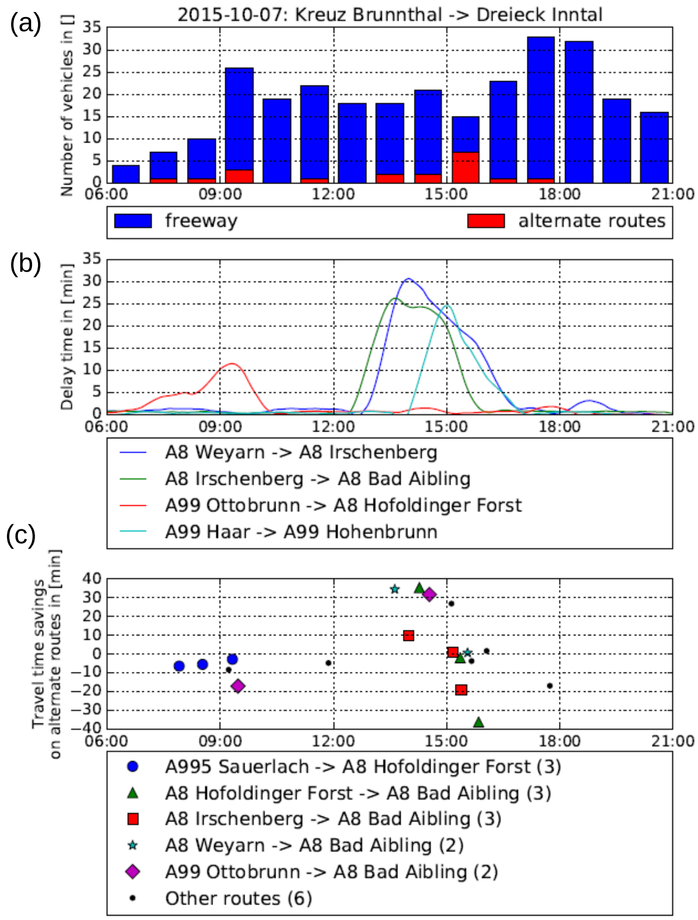

Fig. 4 Traffic jam on the A8 between Weyarn and Bad Aibling (direction: south) and on the A99 on 2015-10-07: (a) Number of vehicles per hour on the main route with traffic jam and on alternate routes. (b) Delay time on freeway due to traffic jam. (c) Travel time savings on alternate routes.

Having a closer look on the heavy jam between Weyarn and Bad Aibling, it is eye-catching that more vehicles take alternate routes from 15:00h to 16:00h than from 13:00h to 15:00h. While the first vehicles taking alternate routes save up to 30 minutes of travel time, the later vehicles take nearly the same travel time on the alternate route or even lose travel time. So in this case the travel time saving does not correlate with the ratio of vehicle on alternate routes. The ratio of vehicles to alternate route to main route reaches a maximum of 47% between 15:00h and 16:00h.

Both examples show the importance of the correct timing. Only during the emergence of the congestion on the main route the travel times on the alternate routes are shorter. With longer lasting congestion on the main route, the traffic flows on alternate routes and thus the travel times are also increasing. But on large parts of the alternate routes no traffic information is available in most of the vehicles as it is not covered by the TMC location table.

VI. Distribution of Travel Times and Respective Savings

By drawing alternate routes into a diagram as in Figure 5 with travel time on main and alternate routes as the axes of the diagram, two different groups of alternate routes can be identified. There is a bigger accumulation of points with delays up to 30 minutes in the lower left quarter of the diagram, and a smaller accumulation on the lower right quarter with delays of around 60 minutes.

It can be seen in Figure 5 that a significant delay on the freeway is necessary to save travel time on alternate routes. Vehicles on alternate routes with around 60 minutes delay on the freeway at the same time are always faster, while with less minutes of delay they are evenly distributed around the equal travel time line. When there are delays of only up to 10 minutes on the freeway, most of the alternate routes are not faster or even slower. With delays of around 30 minutes, some travel time can be saved by the usage of alternate routes. However, there are also some points with a delay of around 30 minutes on the freeway, but still the alternate route is not faster than the highway. This means that the higher traffic on the alternate route also causes delay on the alternate route. Especially on alternate route with long travel times a significant delay on the freeway is required in order to be able to still achieve shorter travel times on the alternate route.

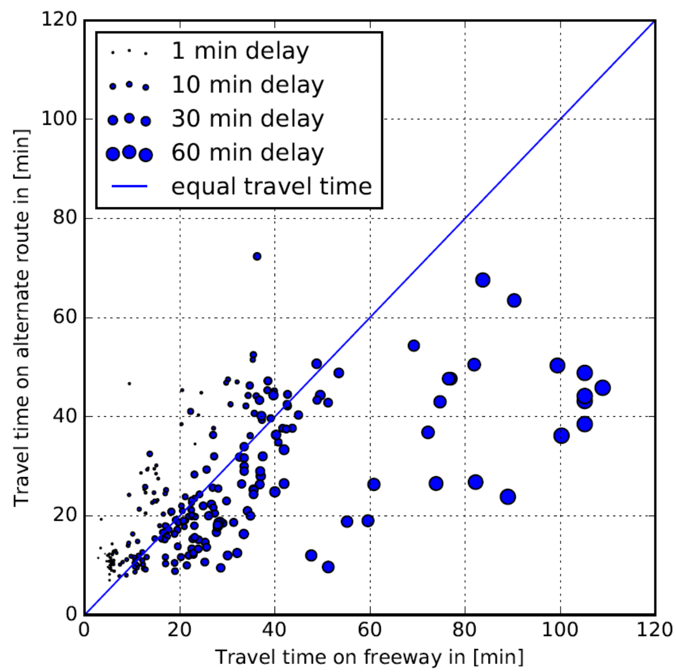

Fig. 5 Scatter plot of vehicles with alternate routes: theoretical travel time on the freeway route is entered on the x-axis and empirical measured travel time on the alternate route is entered on the y-axis. The size of the marker corresponds to the delay due to the traffic on the freeway.

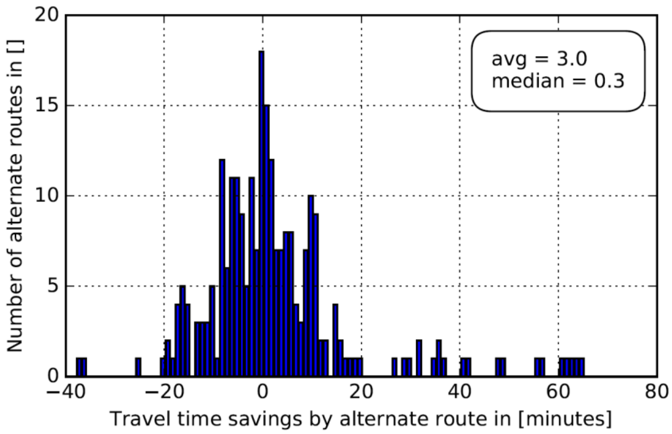

Fig. 6 Distribution of the travel time savings.

The distribution of all travel time savings in Figure 6 shows a balanced distribution with median 0.3 minutes. This means that 50% of all vehicles save 20 seconds or less on the alternate route. The average travel time saving is with 3 minutes slightly higher than the median, as the average is raised by a few alternate routes with 20 to 70 minutes travel time advantage. Also in this diagram the two groups from Figure 5 are clearly distinguishable: The majority of vehicles on alternate routes are equally distributed around 0 minutes travel time saving. But there are also a few vehicles with significant travel time savings by the alternate route.

VII. Conclusions and Future Research

In this paper the usage of alternate routes to bypass congested freeways is studied on an exemplary road network based on individual data from a larger fleet. It is empirically shown for the observed vehicle fleet that during the evaluated time period and in the selected road network, no significant travel time savings are achieved by driving on alternate routes. In the given examples it can be seen, that the first vehicles on alternate routes due to congestion can save significant travel time. Vehicles moving later to alternative routes often do not profit from the alternate route as the congestion on the freeway and thus the delay is already decreasing. For severe traffic jams with more than 30 minutes delay it is in all cases better to drive on alternate routes.

So there is a potential for future navigation systems to further optimize the travel time of car drivers by better decisions for or against an alternative route. This can be achieved by increasing the coverage of traffic information messages to road segments outside the TMC location table with topology-based location reference methods like OpenLR [16]. Another option is the route computation on the backend server and transmitting the route back into the vehicle. Then all restrictions on the encoding of traffic information vanishes.

Furthermore, the official permanent detours marked by traffic signs can be validated by this analysis. It might be shown, that the chosen alternate routes mostly coincide with the officially declared detours by national road authorities.

From traffic network management it has become clear that dynamic route guidance requires a balanced and centralized approach where the network capabilities are taken into account. The possible alternate routes with small road capacity have to be advised properly as the travel time might change rapidly with higher load due to rerouting.

For future research also the real time traffic information of the traffic service provider should be taken into account for the analysis as this is the basis for drivers to decide whether they take an alternate route or not. Another aspect for future research could be the empirical analysis of fuel and/or energy consumption on alternate routes compared to the main routes.

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