TRAVEL TIME ADVANTAGES BY DYNAMIC ROUTE GUIDANCE IN GERMANY: STATUS QUO AND IMPROVEMENT POTENTIAL

Urte Helling  
DaimlerChrysler AG, Sindelfingen/Germany  
urte.helling@daimlerchrysler.com

Joerg Schoenharting  
University of Duisburg-Essen, Essen/Germany  
joerg.schoenharting@uni-due.de

1. INTRODUCTION

Distance travelled by motor vehicles in Germany is increasing all the time. The number of trips made by individuals remains constant at an average of three per day, yet the distances travelled per trip are becoming continuously longer. This growth in passenger-kilometres mainly involves motorised individual traffic, in other words primarily passenger cars - the numbers of registered vehicles in Germany is still on the increase [BMVBW (2004), BBR (2005)].

This increase in kilometres driven by passenger cars adds to the capacity problems on German roads: many sections of motorway must be considered overloaded [VDA (2003)] based on standards of appropriate measurement. Stationary and queuing traffic are becoming regular phenomena and increasing in intensity. They are not only a nuisance, they cause significant costs to both the national economy and the drivers affected through time lost, safety disadvantages and increased fuel consumption.

Investigations reveal that traffic problems in the motorway network are mainly caused by accidents, construction work and existing capacity bottlenecks, each of which is responsible for about one third of stationary and queuing traffic [Ober-Sundermeier (2004)]. Traffic problems thus occur regularly or at random, depending on the cause. Dynamic information about both current traffic conditions and those to be expected is thus becoming increasingly important.

Commuter traffic at peak times is particularly badly affected by traffic problems. Studies have shown that stationary traffic causes a total time loss of 1 billion hours per year [BMW (1997)] or an individual time loss of 20 minutes a day for every employee in Germany [ADAC (2005)].

Against this background, the sales of dynamic route guidance systems are growing steadily [ADAC (2002)]; in the meantime they have become standard equipment in large numbers of premium and mid-range cars. These systems primarily aim to reduce driving time by avoiding congested areas on the
original route: "driving time advantage" [cf. e.g. Lappin (2000)]. If it is not possible to avoid the area, the benefit of the devices is information about the delayed time of arrival at the destination: "information advantage" [cf. e.g. Zackor (1999)].

Thus although it is evident that dynamic information is becoming more and more important, as already explained, the question remains as to whether, under today's basic traffic conditions (road network structure, utilisation of the network capacity and quality of traffic messages received), dynamic route guidance systems are actually in a position to exploit the potential benefits described.

2. OBJECTIVE OF THE PAPER AND METHODICAL APPROACH

2.1. Objective

The objective of this paper is to answer two questions:
1. What driving time or information advantages do dynamic route guidance systems provide with the current quality of traffic messages available in Germany?
2. What potential benefits do dynamic route guidance systems have with optimum message quality? (This optimum message quality will be termed "ideal route guidance".)

2.2. Procedure

The question as to how great the potential benefit of reducing driving time in the event of a traffic problem by selecting an alternative route depends to a large extent on the capacity utilisation of the road network and the availability of an alternative route. Therefore the load on and density of the German motorway network will be examined first. The second variable which determines the possible degree of utilisation of this potential benefit concerns the quality of traffic messages. This is determined using an empirical study. Suitable software is then used to simulate driving time and information advantages on selected routes taking the current quality of traffic messages into account. The results are discussed on the basis of an exemplary route (Duesseldorf-Cologne), summaries presented for nine further routes and the results then extrapolated for the whole of Germany.

2.3. Specifications

The following specifications apply:
- Road network:
  The investigations are concerned exclusively with the motorway network, since this is the only part of the road network where traffic messages for dynamic route guidance systems are completely available.
- User group:
  The investigations are carried out for the user group "commuters", who
regularly travel, e.g. between place of domicile and work, at fixed times of day. The simulation calculations assume the outward journey at 7.30 h and the homeward journey at 17.00 h.

- **Investigation period:**
  The investigations cover the period of one year. The year 2000 was chosen, since a traffic message archive was available for this year for the simulation calculations.

3. **TERMS AND DEFINITIONS**

3.1. **Route guidance systems**

On the basis of a digital map and the vehicle position (determined using Global Positioning System GPS and vehicle sensors), route guidance systems determine the optimum route (usually optimum in terms of time) to a destination selected by the user. The driver is guided along the route either by arrows ("turn-by-turn") or a visual map and spoken phrases. A distinction is made between the three following types of route guidance systems:

- **Static route guidance system (SRG)**
  This calculates the driving time and route exclusively on the basis of a digital map with the segment distances and speeds statically stored in the system. There is no current traffic information available.

- **Dynamic route guidance system (DRG)**
  This integrates traffic messages in the route calculation before and during the trip. Today, these can usually be received via the RDS/TMC radio channel. Extended driving time along the network segments caused by traffic problems is taken into account and leads to a re-calculation of driving time and/or driving route if appropriate. Traffic messages can potentially contain current message errors.

- **Ideal route guidance system (IRG)**
  This corresponds to a large extent to the dynamic route guidance system, but the assumption applies that the traffic messages are correct (optimum message quality).

3.2. **Routes**

- **Normal route (NR)**
  The original route between the starting point and destination is termed normal route. It is determined by the static route guidance system under the assumption of free flowing traffic.

- **Alternative route (AR)**
  If the normal route is not the quickest route due to traffic problems, all the routes which, taking network loads into account, represent a quicker connection between starting point and destination, are alternative routes.

- **Ideal route (IR)**
  The ideal route represents the quickest alternative route, taking network loads and optimum message quality into consideration. It corresponds to the best route of the ideal route guidance system.
3.3. Driving times

- Estimated driving time (EDT):
The driving time estimated at the start of the journey. The route guidance system uses the information available (road map, traffic messages if applicable) before the trip is started to estimate the driving time required for the route selected and indicates this to the driver.

- Actual driving time (RDT):
The actual driving time indicates how long the vehicle actually required along the selected route to reach the destination. In the case of static and dynamic route guidance and traffic problems along the normal route, the actual driving time can be significantly higher than the estimated driving time.

3.4. Benefit

- Driving time advantage (TA)
This indicates how much quicker the dynamically or ideally guided vehicle arrives at the destination in comparison to the statically guided vehicle. It is defined as the difference between the actual driving times and occurs when traffic problems are avoided on the normal route through the DRG system.

- Information advantage (IA)
This occurs where there is no diversion available for traffic problems on the normal route. The driving times of the systems correspond, but in contrast to the statically guided driver, the driver with a dynamic or ideal route guidance system is informed about the delay due to stationary or queuing traffic (increase in comfort thanks to better ability to plan further actions and appointments).

If the traffic problems on the normal route could be avoided, the driving time advantage is relevant and the information advantage is not evaluated.

4. STRUCTURE AND CAPACITY UTILISATION OF THE NETWORK

4.1. Structure

The evaluation of the motorway network reveals extreme differences in density within Germany, depending on the specific region involved (Figure 1). The network only seems dense enough (network density 0.04 - 0.06 km/km²) to have alternative routes available for commuters in the Rhine-Ruhr and Rhine-Main conurbations.

In the other parts of Germany, particularly in the eastern states (Mecklenburg-Vorpommern, Brandenburg, Saxony, Saxony-Anhalt and Thueringen), alternative routes to avoid traffic problems in the motorway network are only available in extremely rare cases.

4.2. Capacity utilisation
The second important aspect when considering route planning concerns capacity utilisation within the network. For the investigation of network loads caused by stationary and queuing traffic, a RDS/TMC traffic message archive provided by the German Association for Traffic Data (Deutsche Gesellschaft für Verkehrsdaten DDG) from the year 2000 is evaluated. The main rush hours between 7.00 and 9.00 h and 15.00 and 18.00 h were examined. These messages are transferred into average increases in driving time during the whole of the year 2000.

Figure 1 shows the results. The conurbations Rhine-Ruhr and Rhine-Main in particular reveal great increases in driving time. An examination of the network segments based on problem lines revealed for these regions that the probability of experiencing free traffic flow at peak traffic times is significantly lower than the probability of experiencing problems with traffic flow [Rehborn

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Normal routes are probably often affected by problems in these regions; it is questionable, however, whether alternative routes can be found and driving time advantages exploited in these areas despite high network density, because potential alternative routes are also usually extremely busy. In Mecklenburg-Vorpommern, Saxony and Brandenburg on the other hand, the load on the roads is hardly excessive even at peak traffic times, which means increases in driving time are not to be expected.

5. QUALITY OF TRAFFIC MESSAGES

5.1. Definition of message quality

For the evaluation of message quality with regard to making a route guidance system dynamic, the mapping of the increase in driving time on the motorway sections caused by congestion is important, because the resulting speed on the segment serves as a basis for route calculation and is thus the central factor of influence for correct calculation. This includes both correct mapping of the average speed currently possible through a status description as well as the correct mapping of the spatial extent of the event on the segment in question. Comparison of the driving times announced by two message archives (Deutsche Gesellschaft für Verkehrsdaten DDG and Westdeutscher Rundfunk WDR) for the segment illustrated as an example in Figure 2 shows that significant differences can exist here: agreement can be found only at the times marked by arrows.

![Figure 2: Driving times on the segment Cologne-Bocklemund to Cologne-Loevenich on 6.9.2000 according to the archives from DDG (black) and WDR (white) [from Helling (2006)].](image-url)
This aspect of a message error related to driving time and the effect it has on routing has not been taken into account in the common definitions of message quality or in previous investigations [refer here to Bogenberger (2003), DDG (2000), WDR (2003)]. For this reason, a "route guidance-specific message quality" on the basis of the message fault related to driving time is defined (Figure 3):

The message quality is said to be optimum (TMQ=100%) if the announced and real increase in driving time are identical. Taking this point as a basis, the message quality should decline linearly and symmetrically to both sides to the points where in the case of a real increase in driving time either no increase or twice the increase are announced. In the case $\Delta T_{\text{announced}} > 2\Delta T_{\text{real}}$ the message quality is defined constantly as zero.

![Figure 3: Route guidance-specific definition of message quality – basis for the evaluation is the announced increase in driving time](image)

5.2. Investigation of message quality

Test drives were carried out in the Stuttgart area to determine real driving times. This area has a high traffic load, in other words increased probability of traffic obstructions, and at the same time a representative distribution of measuring sensors installed which have a direct influence on the quality of traffic messages. A total of around 4,000 "segment driving times" were recorded on the motorways between Ludwigsburg and Herrenberg (A81) and between Pforzheim and Wendlingen (A8) for 44 segments between March and October 2004. In 300 cases a respective traffic message was available: the increases in driving times resulting from actual measurement and the increases announced were compared.

Figure 4 illustrates the result of the empirical investigation. Only 8% of the messages considered announced a segment driving time that was approximately correct, which in this case means with a difference in increased driving time of less than 10%. In 24% of the cases the quality was found to be less than 10%. This investigation revealed the average message quality to be 35%.
6. DETERMINATION OF TIME AND INFORMATION ADVANTAGES

6.1. Conception of the investigation

A suitable simulation environment is used to calculate routes as well as estimated and actual driving times using static, dynamic and ideal route guidance and various message qualities in the German road network:

- Driving times with static route guidance:
  Route and estimated driving time (EDT) are estimated on the basis of the road maps with their attributes of length and free driving speed. The actual driving time (ADT) along the pre-selected route is calculated taking possible extensions in driving time on the basis of a traffic message archive from DDG from the year 2000 into account, where the messages are taken to be "real" for the purposes of the simulation.

- Driving times with ideal route guidance:
  Route, estimated and (identical) actual time of arrival (EDT=ADT) are calculated using road map and DDG message archive.

- Driving time with dynamic route guidance:
  Route and estimated driving time (EDT) are based on the road network and DDG message archive, the resulting increases in driving time of which are "falsified" systematically by the empirically determined message quality (35%). The actual driving time on this route is calculated using the driving times from the original DDG archive with the messages taken as "real" for the simulation.
The differences between dynamic or ideal route guidance and static route guidance – considered over the period of one year – result in the average benefit advantage.

Trips made by commuters on ten motorway routes are simulated (see Figure 5). These routes were selected on the basis of the criteria "network density" and "network load" in such a way that a subsequent regionally differentiated transfer of the results to the whole of Germany is possible.

Figure 5: The ten motorway routes examined – grouped according to network density and network capacity utilisation [from Helling (2006)].

6.2. Procedure and results – Example "Duesseldorf ↔ Cologne"

In freely flowing traffic, the route between the motorway junctions Duesseldorf-North and Cologne-South comprises a distance of 37 km along the A44, A3 and A4 motorways (Figure 6: blue route). In free-flowing traffic, the driver will take 32 minutes. Congestion can be avoided by taking one of the alternative routes shown.

Individual consideration: Figure 6 illustrates the situation for the morning drive from Duesseldorf to Cologne on Monday, 14.02.2000 at 7.30 h. There were several points of stationary and queuing traffic on the road network on this day. This congestion led to an increase in driving time of 27 minutes along the normal route and resulted in a total driving time of 59 minutes instead of 32 for drivers with static route guidance. It was not possible for drivers with dynamic or ideal route guidance to avoid the traffic problems in this case, because the alternative routes were also affected by problems at this particular time. An information advantage of 29 minutes was gained in comparison to drivers with static route guidance.
Consideration over one year: The "representative commuter" made a total of 388 trips between Duesseldorf and Cologne within the course of one year. Almost 2/3 of these trips (244 trips) were affected by stationary or queuing traffic along the normal route. Table 1 shows a comparison of the simulation results for the three route guidance systems:

- Drivers with static route guidance lost a total of 68 hours to traffic problems (average of 17 minutes per congestion) during the year and required a total of 276 hours for their trips.
- Assuming a message quality of 35%, drivers with dynamic route guidance required 262 hours (driving time advantage 14 hours or 5%). They followed diversions on 89 days and drove 1,279 km (5%) further. In relation to the total number of 388 trips, 25% (98 decisions) of the routes were not chosen optimally from the point of view of time.
Drivers with *ideal* route guidance required 245 hours (driving time advantage 31 hours or 11%). They followed correct diversions on 159 days and drove 1,405 km (6%) further. In connection with the remaining 85 congested trips without diversion, they had an information advantage of 14 hours.

<table>
<thead>
<tr>
<th>Effects between Duesseldorf and Cologne</th>
<th>SRG</th>
<th>DRG</th>
<th>IRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of diversions</td>
<td>[-]</td>
<td>0</td>
<td>89</td>
</tr>
<tr>
<td>Driving time lost due to congestion</td>
<td>[h]</td>
<td>68</td>
<td>54</td>
</tr>
<tr>
<td>Annual driving time</td>
<td>[h]</td>
<td>276</td>
<td>262</td>
</tr>
<tr>
<td>Driving time advantage in comparison with SRG</td>
<td>[h]</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>[%]</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Information advantage in comparison with SRG</td>
<td>[h]</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Detour in comparison with SRG</td>
<td>[km]</td>
<td>0</td>
<td>1,279</td>
</tr>
<tr>
<td></td>
<td>[%]</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

*Table 1: Simulation results on the "Duesseldorf-Cologne" route for the three route guidance systems*

**Further evaluations:** The comparison between results from the morning and evening revealed two things: (i) the normal route is affected by traffic problems in the evening significantly more frequently (more than twice as often as in the morning) and (ii) diversion possibilities are more frequently available - relatively as well - in the evening: whereas diversions were possible in 53% of the mornings with traffic problems along the normal route, this figure rose to 70% for the evenings. The average driving time advantage was 18 minutes in the morning and 16 minutes in the evening per diversion. This illustrates that the network is extremely full in the evening in particular, but that the dynamic route guidance system nevertheless provides possibilities for optimising driving time.

Varying the time of departure in the morning also shows that the driving time advantage determined of ideal route guidance in comparison with static route guidance increases the later the time of departure. This can be explained by the fact that the traffic load on the network at this later point in time is much more frequent and heavier (see Figure 7), which means drivers with static route guidance lose a significant amount of time whereas drivers with ideal route guidance can be diverted. Ideal route guidance can keep the driving time between Duesseldorf and Cologne for the time between 8.00 and 9.00 h constant to 135 hours/year, whereas the driving time of drivers with static route guidance increases from less than 160 to above 170 hours/year.
6.3. Results of the ten routes investigated

*Figure 8* shows the driving time and information advantages due to dynamic and ideal route guidance determined for all ten routes investigated.

- **Dynamic** route guidance (current message quality)
  Driving time advantages (between 2 and 15 hours) were determined for six routes. In two cases no driving time advantages were achieved. In two further cases there was a driving time *disadvantage* in comparison with static route guidance. The diversions were linked to an additional distance travelled of up to 9% (70 to 1,226 km further a year).

- **Ideal** route guidance (optimum message quality)
  Information advantages were determined for all ten routes; they were up to 100 hours a year. Driving time advantages were determined for nine routes. The values were between 1 and 34 hours a year (potential benefit: up to 16% reduction in driving time compared with static route guidance). The diversions led to additional distances of up to 11% (77 to 3,722 km further a year).
Figure 8: Driving time and information advantages with dynamic and ideal route guidance on the ten routes investigated [from Helling (2006)]
7. BENEFITS AND POTENTIAL OF ROUTE GUIDANCE IN GERMANY

7.1. Current benefits of dynamic route guidance in Germany

The results of the ten examined routes were used to carry out a national qualification of the benefit of dynamic route guidance systems in Germany on the basis of the classification of these routes (network density, network load). Figure 9 shows the results on the map:

Figure 9: Driving time advantages (red) and information advantages (yellow) with ideal route guidance (benefit potential) in Germany: driving time advantages through dynamic route guidance are given in the conurbations in particular. [from Helling (2006)]

- Despite frequent and heavy congestion, alternative routes for diversions can often be found in the Rhine-Ruhr and Rhine-Main regions. This results in driving time advantages which are not greater than 5% on an annual average with the current message quality, however.
• Motorways in and around centres and cities as well as some transit routes have similar driving time increases, but there is a lack of alternative routes to avoid this in these cases. Accordingly, mainly information advantages can be achieved in Hamburg, Bremen, Oldenburg, Hanover, Berlin, Dresden, Chemnitz, Hof, Ulm, Munich, Regensburg, Nuremberg, Freiburg, Saarbruecken, the eastern Ruhr region, in the Frankfurt area and the regions Wuerzburg-Frankfurt and Stuttgart-Mannheim. In these areas, annual driving time advantages are only around 1 to 2%.

• Only slight driving time increases were determined for the rest of the country. Accordingly - and due to a lack of alternative routes - only a minor benefit in the form of an information advantage of a few hours a year can be expected there (in particular for central and eastern Germany: Thueringen, Saxony-Anhalt, Saxony, Mecklenburg-Vorpommern, North-Hesse, East Westphalia).

7.2. Improvement potential for dynamic route guidance

The simulation calculations show in comparison between dynamic and ideal route guidance that an improvement in message quality is accompanied by an increase in benefit of dynamic route guidance. The investigations resulted in the functional correlations between driving time advantage and message quality illustrated in Figure 10.

Figure 10: Correlation between driving time advantage and message quality - an increase in message quality from the current 35% to 70% seems to be a sensible option for dynamic route guidance [from Helling (2006)]

In comparison to the case of optimum message quality, the current message quality of 35% - as determined in the empirical study - only leads to around
40% of the maximum possible driving time advantage being exploited. In other words, an improvement of message quality (and thus improvement of the whole dynamic process of route guidance) from 35% to 100% effects an improvement potential of dynamic route guidance and driving times respectively of 250%.

It is notable that the increase in driving time advantage is progressive. This means that - from today's point of view - even small increases in message quality are efficient and will lead to major improvements in driving time advantage. Bearing this in mind, it seems sensible to double the message quality from the current 35% to 70% which would have the effect of increasing the driving time advantage from 40% to 95% of the maximum possible benefit.

8. SUMMARY AND OUTLOOK

The investigation set out to answer the questions posed initially about the possibility of realising driving time and information advantages by means of dynamic route guidance systems and their maximum benefits (benefit potential with optimum message quality).

The calculations show that in many parts of Germany, dynamic route guidance systems could realise driving time or at least information advantages for commuters if optimum message quality were available (ideal route guidance). They are evaluated as beneficial in the conurbations Rhine-Ruhr and Rhine-Main. In these areas, the high network density often provides alternative routes for avoiding congestion - despite a high traffic load. Driving time advantages of 5 to 15% compared with static route guidance can be realised.

In regions with average network density and increased traffic loads (e.g. agglomerations in North and South Germany), such systems are evaluated as beneficial with regard to the information advantage. In regions with low traffic loads such as in North-East Germany, hardly any benefits are to be expected, particularly no driving time advantages.

The current message quality leads to a loss of benefits - in particular with regard to driving time advantages: Driving time advantages of a maximum of 5% can be realised in the conurbations mentioned. Driving time disadvantages were also recorded: in the case of faulty messages, the driving times of drivers with dynamic route guidance can even exceed those of drivers with static route guidance. An improvement in message quality from the current 35% to 70% would lead to a significant improvement of dynamic route guidance (95% of the potential benefit could be exploited).

There is a series of starting points for the improvement in message quality and thus the whole process of dynamic route guidance:

- Explicit messages about speeds being driven (km/h) rather than synonyms (stationary traffic, queuing traffic, etc.)
- Explicit transmission of "free flow" messages (such as in Japan, for example)
• Extensive expansion of data recording beyond the motorway network, in particular recording of the diversion routes away from the motorways
• Transmission of construction work, their capacity restrictions and speed limits
• Quicker recording, interpretation and dispatch of traffic data
• Specification-conform message decoding in the vehicle

Cooperation between message providers, manufacturers of navigation systems and standardising bodies is required to achieve efficient progress in this inter-disciplinary area.

Traffic messages via the RDS/TMC channel are now available in most European countries, making dynamic route guidance possible in these countries. In future, the investigations - initially carried out for Germany - should be extended to cover other countries and their specifics concerning network density, traffic load and traffic message quality and availabilities. The results are extremely important for directed sales (manufacturer) and application (customer: decision to buy) for systems in existing and new markets.

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