Route Choice in Road Networks - Observing and Modelling Route Choice

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Route Choice in Road Networks - Observing and Modelling Route Choice

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Abstract: Until now transport planners and modellers have little information on the actual route choice in road networks as route choice is difficult to observe. The paper presents various techniques for observing route choice (floating car data, mobile phone data, automatic number plate recognition systems, bluetooth detection) and shows results of route choice observations. Based on the analysis of the observed route choice and based on the characteristics of travel assignment models it describes shortcomings and formulates requirements for modelling route choice in a traffic assignment model.

Key Words: traffic assignment, route choice behaviour, route choice surveys

1 Introduction

The traffic state in a transport network at a particular point in time is the result of complex decision processes of individuals. Individuals continuously take decisions that influence their mobility behaviour and thus the traffic in a transport network. They range from long-term decisions to short-term and spontaneous decisions. Long-term decisions concern the residence location choice, the work place choice or the decision to purchase a vehicle. Decisions regarding the activity schedule, the activity locations of a day, the choice of departure time, mode and route are mid-term or short-term decisions. The choice of the travel speed or the lane choice on a motorway are decisions taken at very short notice.

Transport models replicate these traffic related decision processes of travellers. Modelling the decision processes is a prerequisite for analysing and forecasting traffic states in current and future networks. Traditional travel demand models cover the decisions concerning the choice of destination, mode and route. The route choice is embedded in the so-called traffic assignment. A traffic assignment distributes the travel demand between locations in a study area onto the transport network considering constraints determined by the transport supply, especially capacity, time and cost. Traffic assignment models for private transport should fulfil two main requirements:

- They should determine the route choice of drivers in a realistic way thus providing consistent traffic volumes on links and turnings in the network.
- They should provide reasonable travel times for links and turnings.
Additionally traffic assignment models should be fairly fast and should produce robust results, so that minor changes in the demand or in the supply do not result in unexplainable large changes of link volumes.

Traffic assignment models should fulfil these requirements also for a multiclass assignment, where more than one user group (e.g. passenger cars and trucks) is assigned simultaneously. Furthermore they should support volume delay functions which provide realistic delay times at intersections.

As route choice and travel time are difficult to survey it is common practice to calibrate and validate traffic assignment models merely with volumes from roadside link counts. This paper presents in a first step methods for observing route choice in road networks. Then it intends to show differences and similarities between a route choice analysis and a traffic assignment. It briefly explains basic concepts of static and dynamic traffic assignment, identifies some common shortcomings of assignment models and concludes with general recommendations.

2 Observing and Analysing Route Choice

2.1 Methods for Observing Choice

In order to analyze the route choice behaviour of drivers in the road network ideally the following information about a movement is available:

- origin and destination of the trip with departure and arrival time
- spatial course of the route between origin and destination as a series of nodes or links on a digital map
- temporal course of the route as a time-space trajectory
- alternative routes with travel times
- information available to the traveller concerning the movement (e.g. navigation system, traffic radio, roadside travel information)
- context of the route choice (e.g. socio-demographic variables of the driver, trip purpose)

These requirements stand against the actually available methods for monitoring route choice and recording the actual travel time:

1. GPS – Data:
   A number of test persons is recruited and supplied with monitoring devices. The monitoring devices record the movements of the persons or the vehicles with the help of a GPS-logger. The data are collected from the test person or directly transmitted to a server. This method permits to survey a relatively small sample of travellers during a limited survey period. It is easy to collect additional information on the test persons and the context of their route choice as the persons can be contacted directly. In MANDIR et al [8] such a survey is described.

2. Floating Car Data (FCD):
   FCD are transmitted to a central server directly from the navigation systems of specially equipped vehicle fleets. FCD are primarily used for detecting disturbances in
the road network and not for tracking individual vehicles. Access to FCD permits to continuously observe route choice for a sufficient sample of car drivers. Because of data protection it is usually not possible to connect FCD to attributes of individual drivers.

3. Floating Phone Data (FPD):
FPD recorded in the cellular phone network may be used to derive time-space trajectories of car travellers. Data sets from mobile phones in stand-by mode collected over a longer time period and longer distances provide the basis for continuously observing route choice behaviour for a relatively large sample of car drivers. FPD has limitations, if alternative routes show a similar signal pattern in the cellular phone network or if routes are short. SCHLAICH et al [9] describe one approach for generating trajectories from FPD.

4. Automatic Number Plate Recognition (ANPR):
With the help of ANPR-systems the number plates of vehicles at selected cross sections in the road network are detected. Comparing the number plates recorded at subsequent cross sections provides information on the routes and travel times of vehicles. ANPR-systems have a high detection rate between 70% to 100%. If all lanes of a cross section are detected, it is possible to observe a large sample of car drivers. Limitations of the method stem from the relative expensive ANPR-detectors which must be installed at all intersections of interest. More information on ANPR-systems for observing route choice can be found in FRIEDRICH et al [3].

5. Bluetooth Recognition:
Bluetooth recognition works similar to ANPR-systems. Instead of number plates it matches unique MAC-Addresses (Media-Access-Control-Address) of mobile devices using Bluetooth for wireless communication. The main advantage of Bluetooth compared to ANPR is the lower price for the detectors. The main disadvantage is the lower detection rate as only some of the vehicles are equipped with Bluetooth devices.

2.2 Analysing Route Choice - one Example

This chapter briefly summarizes results of a route choice analysis using FPD-trajectories collected during 80 days between June and October 2008 in a study area in South-West Germany conducted by SCHLAICH [11]. Figure 1 shows the study area which covers four major motorways forming a motorway-quadrangle (motorways A5/A6/A8/A81). Between Stuttgart and Walldorf travellers can chose a route via Heilbronn and a route via Karlsruhe. Variable message signs (VMS) inform the travellers about traffic disturbances. From FPD provided by T-Mobile Germany 715,000 FPD-trajectories could be identified travelling between Stuttgart and Walldorf in both directions. As documented in Figure 2 approximately 70% of the travellers use the route via Karlsruhe and 30% the route via Heilbronn. This is reasonable as the route via Karlsruhe is usually 5 to 10 minutes faster than the route via Heilbronn. The route via Heilbronn, however, is recommended by static signs.
Figure 1: Study area with two alternative routes between Stuttgart and Waldorf and the location of Variable Message Signs (VMS).

Figure 2: Route choice over 80 days.

Figure 2 also shows that the share of travellers on each route varies over time. To identify relevant indicators influencing the route choice SCHLAICH [11] estimated the parameters of a Logit-Model. Logit is a distribution model which determines the share of alternative $n$ based on the differences in utility values between the set of all alternatives:
\[ P_j = \frac{e^{V_j}}{\sum_{n=1}^{N} e^{V_n}} \]

where:
\( P_j \) probability of alternative \( j \)
\( V_j \) deterministic utility value of alternative \( j \)
\( N \) number of alternatives

To determine the utility value SCHLAICH uses the following utility function:

\[ V_{j,d} = \alpha_{j,d} + \beta_{VMS} \cdot VMS_{\text{active},d} + \beta_{l_{\text{congestion}}} \cdot l_{\text{congestion},j,d} + \beta_{l_{\text{halting}}} \cdot l_{\text{halting},j,d} \]

where:
\( V_{j,d} \) deterministic Utility of alternative \( j \) in direction \( d \)
\( \alpha_{j,d} \) constant parameter for alternative \( j \) in direction \( d \)
\( \beta_i \) parameters for attributes
\( VMS_{\text{active},d} \) 1, if VMS gives a route recommendation in the \( d \) direction
0, if otherwise
\( l_{\text{congestion},j,d} \) length of broadcasted congestion for alternative \( j \) in direction \( d \)
\( l_{\text{halting},j,d} \) length of broadcasted halting traffic for alternative \( j \) in direction \( d \)
\( j \) alternative (route via Karlsruhe or via Heilbronn)
\( d \) Direction (Stuttgart to Walldorf or Walldorf to Stuttgart)

Using the estimated parameters, the route choice behavior can be plotted on a diagram such as in Figure 3. Such a diagram allows to estimate the impact of broadcasted traffic news and VMS route recommendation. For example, in a situation where the broadcasted congestion via Heilbronn is 5 km longer than via Karlsruhe, a route recommendation from the VMS would increase the share of the through-traffic via Karlsruhe by 6.6% from 77.7% to 84.3%. This means an acceptance of the VMS recommendation of 29.3%.
Figure 3: Influence of congestion and active variable message sign on route choice between Stuttgart and Walldorf in the case of more congestion via Heilbronn than via Karlsruhe.

3 Traffic Assignment Models

3.1 Basic Assumptions

Any traffic assignment model consists more or less explicitly of three submodels:

- Route search model:
  The search model identifies for each origin destination pair a set of reasonable routes.

- Route choice model:
  The choice model distributes the travel demand of one origin destination pair onto the available routes.

- Traffic flow model:
  The flow model replicates the movement of the vehicles along the route and determines the travel time for each link and each route.

Most assignment models are based on three fundamental assumptions:

1. The travellers choose their route based on an impedance or utility function which quantifies the generalised cost of a route. This function combines all indicators influencing the route choice. Common indicators are the travel time, the length and the road tolls of a route.

2. All travellers choose the shortest route. As the route choice determines the distribution of the volumes in the network it also affects the travel time and as a consequence the impedance.
3. The travel demand and the network are in a steady state over a long time period. This fact permits the travellers to know the traffic state and to adapt their choice until the system is in a balanced state. In this state the travellers stick to their route and the impedance on the links and the routes is constant.

For the second assumption two hypotheses are common leading to different types of assignment models:

- **Deterministic user equilibrium assignment (DUE):**
  The deterministic user equilibrium assumes that all travellers have perfect information on the impedance. This leads to a state where all routes between any origin destination pair have equal and minimum impedance while all unused routes have greater impedance (Wardrop [13]). In DUE for the set $N$ of all used routes (demand $q > 0$) the following condition must hold:

  $$\frac{w_i}{w_j} = 1, \quad \forall j = 1...N \text{ and } q_i > 0 , q_j > 0$$

- **Stochastic user equilibrium assignment (SUE):**
  The stochastic user equilibrium assumes that travellers take their decisions with incomplete information concerning the impedance and that each traveller has his own perception of the impedance. In SUE the demand is distributed onto the set $N$ of alternative routes using a discrete choice model (e.g. Logit-Model):

  $$P_i = \frac{e^{\beta \cdot w_i \cdot E_i}}{\sum_{j=1}^{N} (e^{\beta \cdot w_j \cdot E_j})}$$

  where

  $p_i$ probability of using alternative $i$

  $N$ Set of alternative routes

  $E_i$ Independence of alternative $i$, $0 \leq E_i \leq 1$

  $\beta$ scaling parameter

  The independence $E$ considers the fact that two alternative routes may partially overlap. This problem is described in detail by CASCETTA [3].

  DUE can be considered as a special case of SUE, when the variance of the impedance perception is zero.

### 3.2 Static and Dynamic Assignment Models

A traffic assignment is static if the travel demand is distributed onto routes without considering the time of departure. This means that the travel demand is assumed to be constant within the assignment period. Therefore static assignment cannot provide information on the temporal flow of a journey along the route from origin to destination.
meaning, that it is not possible to locate the position of a traveller at a specific point in time.

A traffic assignment is dynamic if the travel demand is distributed onto connections considering the time of departure. This requires information on the temporal distribution of the travel demand and a flow model to describe the movement of the travellers along the route. Applying such a flow model enables the determination of a traveller’s location at a specific point in time.

A dynamic traffic assignment (DTA) offers advantages compared to a static traffic assignment (STA):

- DTA provides information not just on the average traffic volumes and travel times in the assignment period but also on the temporal pattern of the volumes and the travel times. This is especially important in a congested network with distinctive peak hours.
- Most DTA employs a proper traffic flow model. This traffic flow model can either be a macroscopic or microscopic flow model. In macroscopic flow models all vehicles on a link or a link section have the same speed which is derived from the vehicle density using a fundamental diagram. Microscopic flow models simulate the movement of each vehicle. By using a traffic flow model the inflow into a link during a time interval may exceed the outflow thus reproducing the queuing process and downstream metering in a realistic way. In STA inflow and outflow are always the same as STA uses volume delay functions (VDF). VDF determine the travel time in the congested network from the volume-capacity ratio allowing a higher volume on the link than physically possible.

However there are also disadvantages of a DTA:

- DTA requires demand data for each time interval and parameters for departure time choice.
- DTA needs an accurately coded network model as mistakes immediately lead to problems in the traffic flow model.
- DTA is more complex and as a consequence more difficult to understand and to validate.
- In a DTA it is more challenging to achieve a stable equilibrium stage.

A comprehensive discussion of DTA can be found in the Primer for Dynamic Traffic Assignment [12] provided by the Transportation Research Board.

3.3 Shortcomings of Traffic Assignment Models

Like all models traffic assignment models represent a specific abstraction of the real world. This includes simplifications. For example it might be appropriate for planning purposes to assume that all passenger car drivers drive at the same speed or that the time savings for a coordinated signal control are not considered. Nevertheless there are well-known shortcomings which modellers should take into account and which software developers might like to solve. Some of these shortcomings are described in this section.
Choice Set

Most assignment procedures generate the choice set of routes by applying a shortest path algorithm (e.g. Dijkstra's algorithm). This algorithm identifies the shortest path, i.e. the path with the lowest impedance, between an origin node and all destination nodes in a network. To generate more than one path two techniques are common which both alter the impedance of selected links in the network and then perform a new shortest path search:

- **Link Penalty Approach:**
  This approach increases the impedance of links belonging to path identified in previous iterations. In traffic assignment the new impedance can be directly derived from the volumes on the links using a volume delay function.

- **Simulation Approach:**
  This approach randomly alters the impedance using a normal distribution with the impedance as the mean.

Figure 4 shows an example of a network where DUE produces route and link volumes which fulfil the requirements of the deterministic user equilibrium. As the demand is low, the link times do not increase significantly in the loaded network. In this case DUE produces results which are identical with an all-or-nothing assignment. In the example network this leads to a solution with just one route for each direction. As the travel time in the motorway network differs for both directions due to the specific distance in the motorway interchanges the shortest route varies for both directions. This causes unequal link volumes or links with no volume at all, which in this case probably is not realistic. This type of problem occurs in a DUE assignment in parts of the network where the demand is low.

Figure 5 illustrates a problem which may occur in a SUE assignment where the choice set is generated with a simulation approach. Altering the link impedance randomly can produce route segments which are unlikely to be considered by car travellers. In the example shown, the route segment uses the exit and the entry ramp of a motorway thus avoiding the main link on the motorway. This specific problem can be reduced by coding turning penalties for leaving and entering the motorway.
<table>
<thead>
<tr>
<th>Direction</th>
<th>Route</th>
<th>Time in unloaded network</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ➔ 2</td>
<td>via motorway</td>
<td>540</td>
</tr>
<tr>
<td>1 ➔ 2</td>
<td>via rural road</td>
<td>555</td>
</tr>
<tr>
<td>2 ➔ 1</td>
<td>via motorway</td>
<td>570</td>
</tr>
<tr>
<td>2 ➔ 1</td>
<td>via rural road</td>
<td>555</td>
</tr>
</tbody>
</table>

Figure 4: Choice sets in a network.
Figure 5: Routing problems in a route search with a random variation of the link impedance resulting in an alternative route using the exit and entry ramp.

**Route Specific Impedance**

Traffic assignment procedures usually compute the impedance of a route as the sum of the impedance over all network elements (links, turns, connectors) traversed by the route:

\[ w_r = \sum_{s=1}^{S} w_s \]

where

- \( w_r \) is the impedance of a route \( r \)
- \( S \) is the set of network elements along the route \( r \)
- \( w_s \) is the impedance of network element \( s \)

This approach does not support route specific impedance values as they are common in a route choice analysis (see chapter 2.2). Such values are important for modelling through traffic prohibitions, network corridor control systems or simply observed preferences for one route, i.e. a route specific constant. Simple traffic through prohibitions may be modelled by introducing specific user classes with their own trip matrix and impedance function. But for networks with multiple through traffic prohibitions this solution fails. Figure 6 illustrates the problem.
State 1
The links in the quadrangle have the same characteristics so that the impedances are identical. This results in almost equal volumes for route R1 and R2. In reality, however, higher volumes are observed for route R1 as traffic signs recommend this route.

State 2
As route specific impedances are not available the impedances on the links of route R1 are increased in order to shift vehicles from route R2 to R1. This, however, influences the route choice between zone 3 and zone 4 in an undesirable way.

Figure 6: Routing problems resulting from impedance functions with no route specific term.

Route Volumes and Proportionality of Routes
The deterministic user equilibrium assignment provides a unique solution for link volumes. However, it does not provide unique route volumes. As shown in Figure 7 several route volumes can fulfill the requirements of the deterministic user equilibrium. This indicates that the quality of all post-assignment procedures relying on route volumes (matrix estimation, selected link analysis, intersection analysis) depends on the quality of the actual route volumes.
One criterion for a good assignment formulated by BAR-GERA [2] requires that the proportions of flow on alternative route segments with equal costs are the same for all drivers, regardless of their origins or destinations. In the example below this condition is fulfilled by solution 4 and 5. The most likely flow in this example is given by solution 4.

Figure 7: Example network with unique link volumes in user equilibrium (left). For route volumes several solutions fulfil the condition of user equilibrium (right).
Conclusion

Traffic assignment for private transport is probably the most widely used model in transport planning and traffic engineering. Recent developments by BAR-GERA [1], GENTILE [7], FLORIAN [5] or DIAL [4] addressing the problems of convergence, computation time and proportionality of routes reveal the importance of good assignment procedures producing consistent flows on links and routes. These new developments are currently implemented in various software packages and will provide better tools for transport modellers.

Despite these developments any modeller applying an assignment model must take several fundamental decisions:

- **DUE or SUE?**
  DUE is the most commonly used assignment procedure with a sound mathematical background. The new algorithms at least partly overcome shortcomings of a DUE assignment concerning route flows, multiclass assignment and convergence. The main argument against DUE is the assumption of perfect information, which is unlikely even with dynamic car navigation systems. This assumption produces obvious problems in a network with low demand for origin destination pairs with two alternative routes with similar impedances. Here the SUE assumption of incomplete information seems more realistic. It is also in accordance with the discrete choice models applied in destination and mode choice models.

- **Static or dynamic traffic assignment?**
  At first sight it seems obvious that DTA can offer more than static approaches. But DTA can offer a real benefit only if it is based on a high quality network model and demand matrices which are validated for every time interval. A DTA adds considerably to the complexity of an assignment. Consequently it is more difficult to control and requires exceptionally experienced modellers. For most applications a sufficient STA with a peak and an off peak hour assignment is probably more suitable than a deficient DTA.

- **Which network model?**
  Road network models are often derived from digital networks developed for car navigation purposes. These high resolution networks complicate the modelling of delays at intersections and the generation of realistic choice sets (see Figure 5). Maybe the modelling community should consider returning to simpler network models and should develop solutions for automatically converting high resolution networks into simple networks.

In the opinion of the author a future line of development in traffic assignment should explicitly separate choice set generation and route choice. In such an approach the choice set would no longer result from a sequence of shortest path searches performed in each iteration of a the traffic assignment. Instead of that a multipath algorithm would be applied before the assignment to identify the choice set. Suggestions for such an algorithm using an branch-and-bound algorithm and a simplified network model can be found in [9]. This approach would also allow the introduction of route specific impedances.
References


