Node of the Traffic Network ○ **Node on a Route**

Start / Endnode of a Route **Node in the Known Area**

Simulation of Information Oriented Knowledge Models

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Abstract

How does knowledge about the state of a traffic system influence the actions of people within this system?

Traffic planning and management is used to optimize traffic systems, particularly with respect to their efficiency. The individual preferences of road users have to be considered and - if possible - linked with the traffic management system as well as the global aspects of usage. The individual cognition of the current traffic situation exerts an essential influence on the decision-making of road users.

Therefore the key element of this study is to understand the impact of different personal knowledge levels regarding the local and global state of road traffic. To consider these consequences, patterns of different levels of knowledge are constructed and implemented using the simulation toolkit MATSim. Using the evaluations of experimental map based simulation runs, the implications of different levels of knowledge are analyzed and examined. Besides evaluating the quality of knowledge based routes an additional focus lies on the consideration of the simulation results from the viewpoint of traffic-planning.

Keywords

information oriented knowledge models, knowledge based routing strategies, within day re-planning

1   Introduction

Traffic planning and management is used to optimize traffic systems, particularly with respect to their efficiency. The individual preferences of road users have to be considered as well as the global state of the traffic system. A main influence factor on the behaviour of people in a traffic system is their knowledge concerning the system. For instance detailed information on the infrastructure and the traffic load will allow a person to find a route with low traffic and help to avoid traffic jams. In this study the influence of different levels of people's knowledge of a traffic system are modeled and simulated. The key element of this study is to understand the impact of different personal knowledge levels regarding the local and global state of road traffic. Using the results of several sets of simulation runs the implications of different levels of knowledge are analyzed and examined. Additionally it is determined, if there is a correlation between the quality of the created routes and the amount of available knowledge.

2   Knowledge Models

The behaviour of people within traffic systems depends on many different parameters. Probably the two most influencing ones are how familiar a person is with the infrastructure and how much information about the current state of the traffic system is available. Typically a person's knowledge is based on different sources like his or her personal experience, information from a traffic management system or traffic jam warnings from the media. The objective of this paper is to analyze the influence of different knowledge levels of the persons within a traffic system on their executed routes and the traffic system itself. Typical questions in this context are for example "How is the quality of a person's routes affected if the person has only limited information about its environment?" and "How does the traffic load within a traffic system change if the knowledge of the persons in the system is varied?". An attempt to answer such questions is the usage of so called knowledge models. This paper describes the creation and implementation of such a model that respects the two previously mentioned influence factors, information about the current state of the traffic system and knowledge of the infrastructure.

The implemented model is based on the idea that the agents should be able to (re)plan their routes at any time during the simulated day. This allows a person to choose his or her route respecting information about the actual state of the traffic system. The most important part of this information is the number of vehicles that are currently driving on the roads of the network. By using these counts the present travel times of the links can be calculated and used to replan a person's route. This allows a router for instance to detect traffic jams and to create a route that avoids overloaded links.

The second part of the model concerns the knowledge of the infrastructure of the road network. For example a person that lives and works in Zurich will know the roads there and in the surrounding areas but probably not each single road in a different city like Basel or Bern. Therefore a person will use only known streets when planning a route. To take account of this fact, for each person an area is created that contains all parts of the road network that this person knows. By varying the size of these areas, different stages of knowledge can be modelled.

In the described model the creation of the areas of known parts of a road network bases on the usage of a least cost path algorithm. In a first step, the least cost path from point A to point B is created, which results in a route with costs C. To create the known area, the costs C are multiplied with a factor F $\geq$ 1. All routes from A to B that have costs $\leq$ C $\cdot$ F are contained in the known parts of the traffic network. Figures 1 and 2 show an example for a network with a least cost path and the known area within that network.

Figure 1: Traffic Network with Route

Node of the Traffic Network   **Node on a Route**

Start / Endnode of a Route
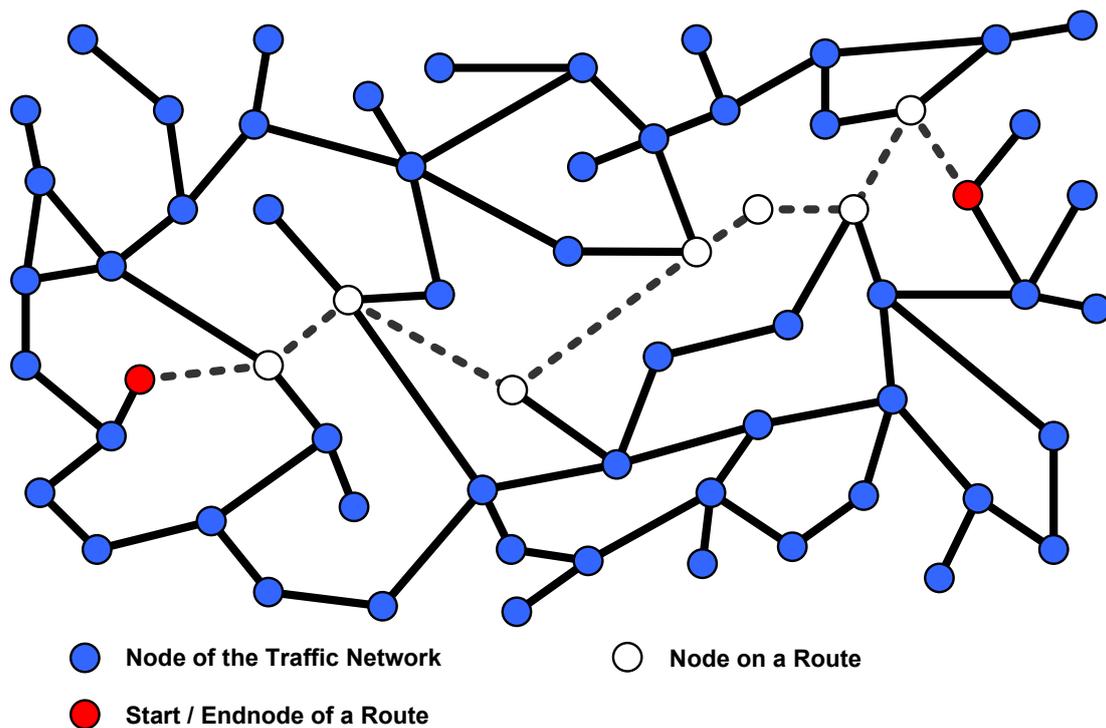
Depending on the way how a person creates the route from a location to a different one, the two knowledge factors have more or less influence. In the following some routing strategies are described and their interactions with these factors are characterized.

- Random Router
  At each node of the network the router chooses randomly the next link. Due to the fact that the router has no memory, it is even possible to turn or create loops.

Figure 2: Traffic Network with Route and Known Area

- Node of the Traffic Network   ○ Node on a Route
- Start / Endnode of a Route   ● Node in the Known Area
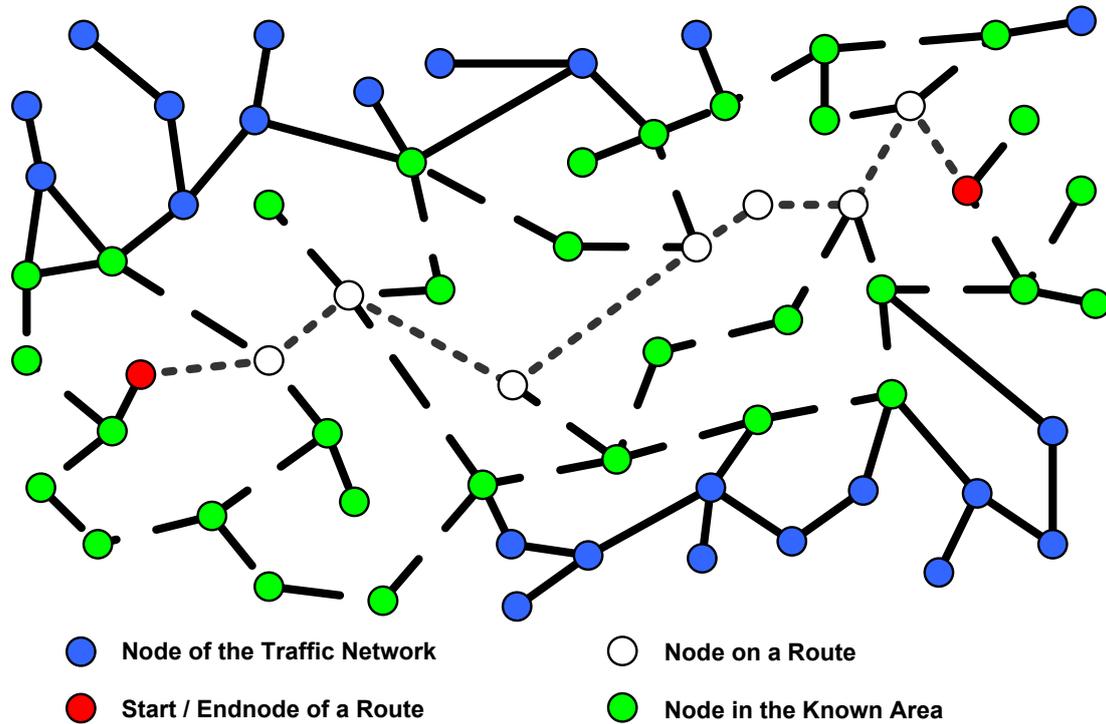
- Tabu Router

  The Tabu Router is an extended version of the Random Router. It also chooses the next link randomly but it knows the previous node in the route and will only return directly to it, if there is no link to another node available.

- Compass Router

  This router uses a compass to generate routes. At each crossing the router chooses that link whose direction is closest to the destination of the route. Depending on the origin and destination of the route and the traffic network it is possible that the router gets stuck in a dead lock and won't find a valid route.

- Random Compass Router

  As its name says, this router is a combination of a Random and a Compass Router. Based on a probability factor the router chooses the next link of a route based on a Random Router or a Compass Router. This should avoid that the router gets stuck in a dead lock.

- Least Cost Router

  There are several implementations of Least Cost Routers available. Commonly used variants implement the Dijkstra algorithm (e.g. Heinrich and Grass, 2006, pp. 251ff). The router uses a cost calculator to determine the costs of the links within a road network. Based on the type of cost calculator different parameters like the travel time or the travel distance are taken into account. Unlike the other described routers a Least Cost Router can also take the actual load of a traffic network in account when creating a route. Typ-

ically jammed streets have higher costs than free ones and so they probability won't be part of a Least Cost Route.

To analyze the influence of replanning the routes during a day (called *within day replanning*) three different routing strategies are used:

- The first strategy is based on the initial creation of routes before the simulation starts. By doing so an empty network is used for the calculation of the travel times and costs what means that a vehicles travels with free speed. This replanning strategy can be compared with the usage of a typical navigation system that uses only structural network information and does not take actual network load in account.
- Another strategy is to create a new route when a person has ended an activity a just starts to travel to the next scheduled activity.
- The last replanning strategy allows a person to replan their route every time the end of a link is reached what means that the next link of a route is chosen just before it is entered.

Due to the different function of the described routers not every combination of router and routing strategy is reasonable. For example a Random Router does not take account of the load of the network so creating an initial route will result in the same route as using a within day replanning strategy. On the other hand a Least Cost Router must be run using within day replanning in order to take the network load into account. The reasonable combinations that are used in this study are listed in table 1.

Table 1: Combinations of Routers and Routing Strategies

| Router / Routing Strategy	Random Router	Tabu Router	Compass Router	Random Compass Router	Least Cost Router
Initial Replanning	x	x	x	x	x
Activity End Replanning					x
Leave Link Replanning					x

3   Simulations

3.1   Implementation

To analyze the behaviour of the described knowledge models they are implemented in the iterative, agent-based micro-simulation framework MATSim that is currently developed by teams at the ETH Zurich and the TU Berlin. It consists of several modules that can be used independently or as part of the framework. It is also possible to extend the modules or replace them with own implementations. Balmer (2007) and Balmer *et al.* (2008) give a detailed description of the framework, its capabilities and its structure. Because of its agent-based approach each person in a traffic system is modelled as an individual agent in the simulated scenario. Each of these agents has personalized parameters like age, sex, available transport types and scheduled activities per day. Klügl (2001), Eymann (2003) and Ferber (1999) give a detailed overview on the topic of (multi-)agent-systems and simulations. Due to the modular structure of the simulation framework the agent's parameters can be extended with parameters for the routing strategy that should be used and the known areas of the road network.

The queue-based traffic flow simulation module that is used for the simulation runs is deterministic and time-step based.[1] Figure 3 shows the structure of a typical MATSim simulation run. After the creation of the initial demand the agents' plans are modified and optimized in an iterative process until a relaxed state of the system has been found and the analyzing of the results can be done.

Figure 3: MATSim Controler Structure
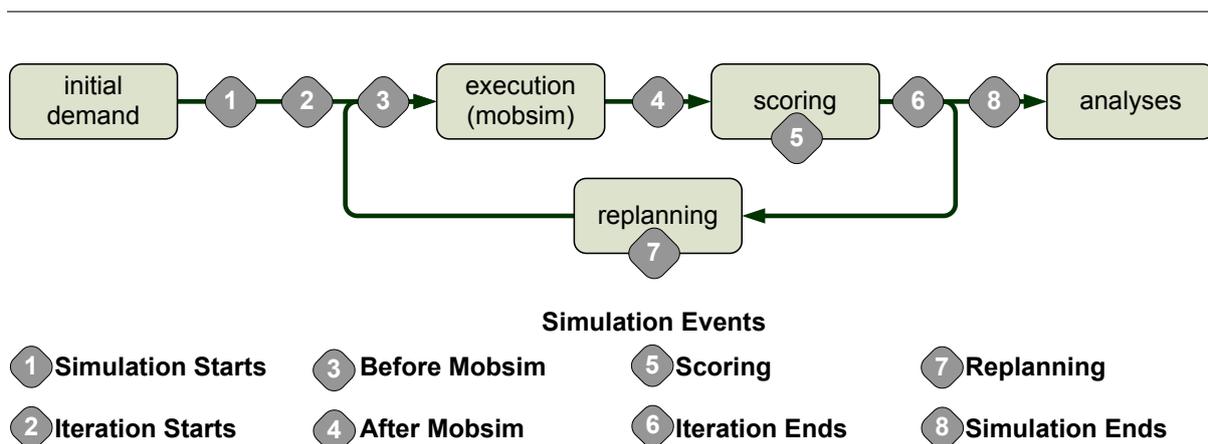
Source: http://matsim.org/docs/controler (own presentation)

Due to the fact that the agents should be able to change their routes depending on the actual load of the traffic system this structure was slightly changed. By extending the simulation module

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[1]java-based re-implementation of the SQSim (Cetin, 2005; Balmer, 2007)

every agent can now decide in each simulated time-step if replanning is necessary. Replanning means in this context that the routes that are used to travel from one activity to another are created again. Changing the length of an activity or its scheduled starting and ending times must be still done before the micro simulation runs. In figure 4 the extensions of the queue simulation module are illustrated.

Figure 4: Extensions of the MATSim Queue Simulation
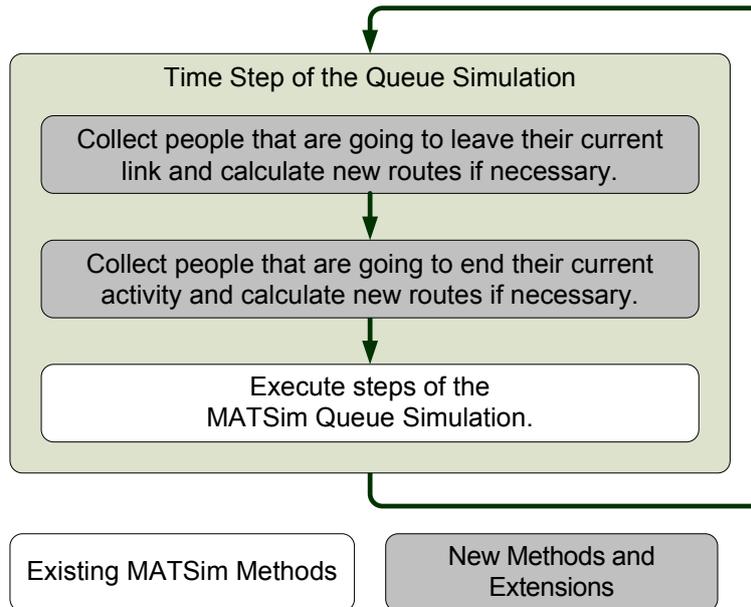
By extending the routing modules the agents are able to consider their knowledge of the traffic system. The routers will take a link only in account if the replanning agent knows the link - otherwise it is ignored. The travel time of a link is estimated by the number of vehicles that are currently driving on the link. A higher count means that the travel time will increase and agents that are creating new routes will possibly try to avoid using that link.

3.2   Scenario

For the simulation runs a 10% square cut of Zurich with an edge length of 100km is used, which includes about 87.600 people and 64.380 facilities. As a constraint, a person is only considered in the simulation, if all scheduled activities take place within the simulated area. The used road network is based on the Swiss National Traffic Network (Vrtic *et al.*, 2003). The focus of this study lies on individual transport so public transport is not simulated. This scenario contains a high amount of traffic, which increases the differences in the mean travel times between the different routing strategies depending on the quality of the created routes.

The underlying, initially used daily plans of the persons result from a simulation run with 150

iterations where the Charypar-Nagel-Scoring Function (Charypar and Nagel, 2005) was used, which created a realistic distribution of the scheduled activities over the simulated time period. The plans of the last iteration are used as input plans for the simulations with the different routing strategies and knowledge levels. The routes in those plans are ignored because they are replaced when the agents do their replanning. For further simulations we freeze the starting and ending times as well as the durations of the activities. We can do this because in this study we are interested in the quality of the created routes and not in an optimal distribution of the activities and traffic over the day. Doing so, allows us to reduce the number of iterations per simulation to one because all the replanning is done during this iteration and any further iteration would produce the same results.

To make the results of the simulations within this study more comparable, a different scoring function is used that only respects the travel time of the executed daily plans. The reason is that typical scoring functions include aspects like the duration of executed activities, travel distance and travel time. Due to the fact that we are only interested in the quality of the routes between these activities, we focus on the trip duration because this is a value that is meaningful measurable and comparable.

As a reference values for the quality of the routes created by the implemented routing strategies an additional series of iterative simulations is run that is using the traditional MATSim optimization strategy without the added within day replanning modules. The agents are able to optimize their routes within their known areas of the network using the travel time based scoring function but they are not allowed to change the duration or the starting and ending times of their activities. The mean travel times per person and day of the relaxed system depending on the size of the known areas are taken as comparative values for the other simulation runs (called *Relaxed System State* in the analysis).

As a second reference value a simulation is run where every agent creates his routes in the morning on an empty network using a least cost path algorithm with a time based scoring function. This simulates a scenario where every driver uses a typical navigation system that knows the entire network but has no information about the traffic load. Any routing strategy that takes the load of the network in account should create better routes - otherwise using the strategy seems to be useless (called *Initial Replanning* in the analysis).

3.3   Analysis of the Results

In the first set of simulations those routers are used that don't take the actual load of the traffic network in account. The agents' routes are replanned initially before the simulation is started. Within day replanning would not produce different results and is therefore not used. The behaviour of the routers is analyzed separately, which means that in each simulated scenario all

agents use the same routing strategy. For each strategy a series of simulations is run where the size of the known parts of the road network of the agents is varied. Doing this allows to determine the influence of the knowledge on the created routes. The results of the simulations are shown in figure 5 which compares the mean travel time per person per day based on the size of the knowledge between the different routers. The Compass Router is not included because almost every agent got stuck and therefore was not able to create a valid route. For comparison additionally the results of the reference simulations are also included.

Figure 5: Comparison of the Initial Routing Strategies
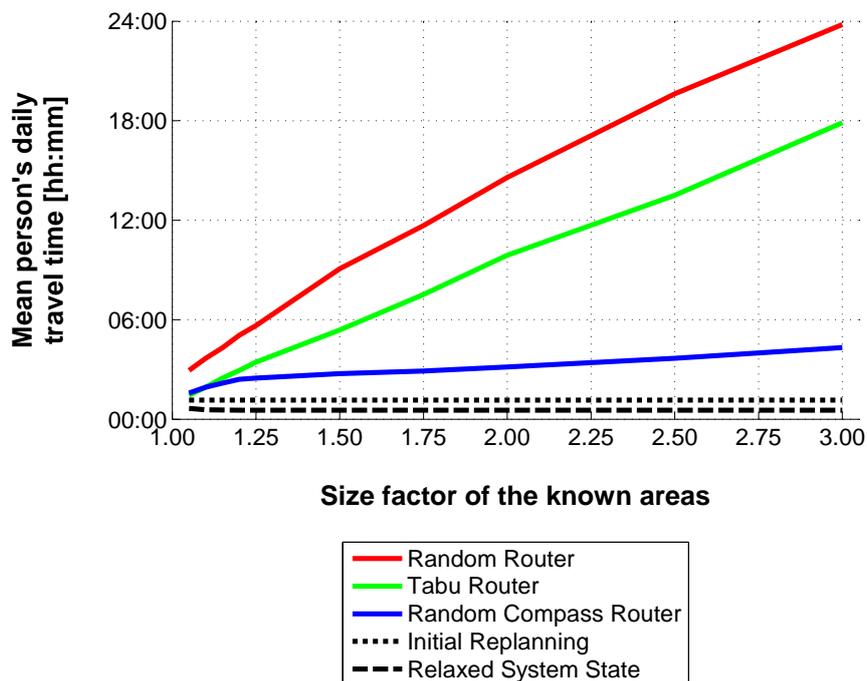
The results show, that even if the persons know only very small parts of the traffic network, the created routes are significantly worse than the ones in the reference simulations. As can be seen in the figure the mean travel times increase almost linearly.

The second set of simulation runs analyzes the behaviour of the traffic if the people take the actual load of the traffic system in account when they plan their routes. To do so, two different replanning approaches are used. People who use the first one replan their route each time they have ended an activity just before they start to travel to the next activity (*Activity End Replanning*). The second approach allows people to update their routes each time they reach the end of a link. This allows them to choose the next link of their route just before they enter that link (*Leave Link Replanning*). Doing this allows an agent that is at a traffic intersection to decide "Link A seems to be congested, so take link B instead". In a real world scenario a routing strategy like this could for example be realized with a traffic management system that communicates with the people to inform them about the actual traffic load of the road network.

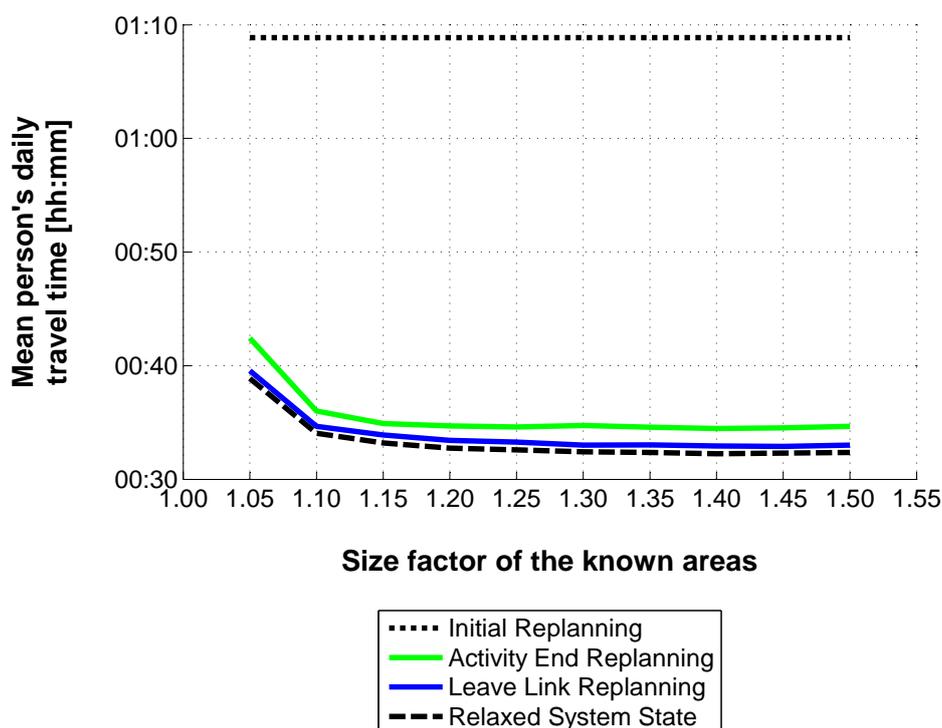Figure 6: Comparison of the Within Day Routing Strategies

Figure 6 again shows the mean travel times of a person as function of the size of the known parts of the road network as well as the values from the reference simulations. As expected, the results of the routing strategies that respect the knowledge of the people lie between the reference values. The considerable longer travel times when using an initial routing strategy are a result of the high traffic load that causes some traffic jam. The persons are able to reduce their travel times until the size of the known areas reach a certain value (size factor of 1.20 in the simulated scenario). If the size factor further increased beyond this value no more noticeable reduction of the travel times can be achieved.

The influence of the size of the known parts of the traffic systems highly depends on the traffic situation. If there is a lot of traffic or even a traffic jam (as in the used scenario), people who know bigger areas are able to find routes that avoid the jammed links which are faster even if the travelled distance is longer. On the other hand persons won't need that knowledge if they are travelling in an almost empty network because their travel time is not influenced by other drivers.

The small time difference between the two within day routing strategies results of the short mean trip duration of about 10 to 12 minutes per trip. Within this time the load of the traffic system usually does not change significantly. Therefore the amount of people that change their route while they are driving is quite small. A very interesting point is that even if people have only a very limited knowledge they are able to create routes that are significantly better than

those created without any knowledge. Using better routes leads to a better balanced traffic load in the network which in turn also reduces the travel times.

The third set of the simulation runs investigates the influence of the distribution of the knowledge among the persons within a traffic system. In the previous mentioned scenario with the traffic management system that informs the people about the network's state, typically not all persons have and/or use the possibility to get information from that system. Reasons could be that they don't have the technical equipment or that they just don't use it because they are afraid that their data could be collected and abused. So in reality the usage of such a system would be somewhere between 0% and 100%. The central question is in which manner the state of a traffic system is affected, if the amount of people with knowledge is varied.

To investigate the behaviour of the traffic system, simulation runs with varying number of people with knowledge are performed. In each simulated scenario there are two groups of people. One group uses a routing strategy that respects the traffic load on the network and one that does not. Due to the fact that we are now interested in the systems behaviour and not in the movement of single persons we ignore the knowledge of areas of the network (now every person knows the entire network) and focus on the knowledge of the network load instead. For both within day routing strategies a set of simulations is run where the amount of people using the router is varied from 0% to 100%.

Figure 7: Mixed usage of Initial and Within Day Replanning
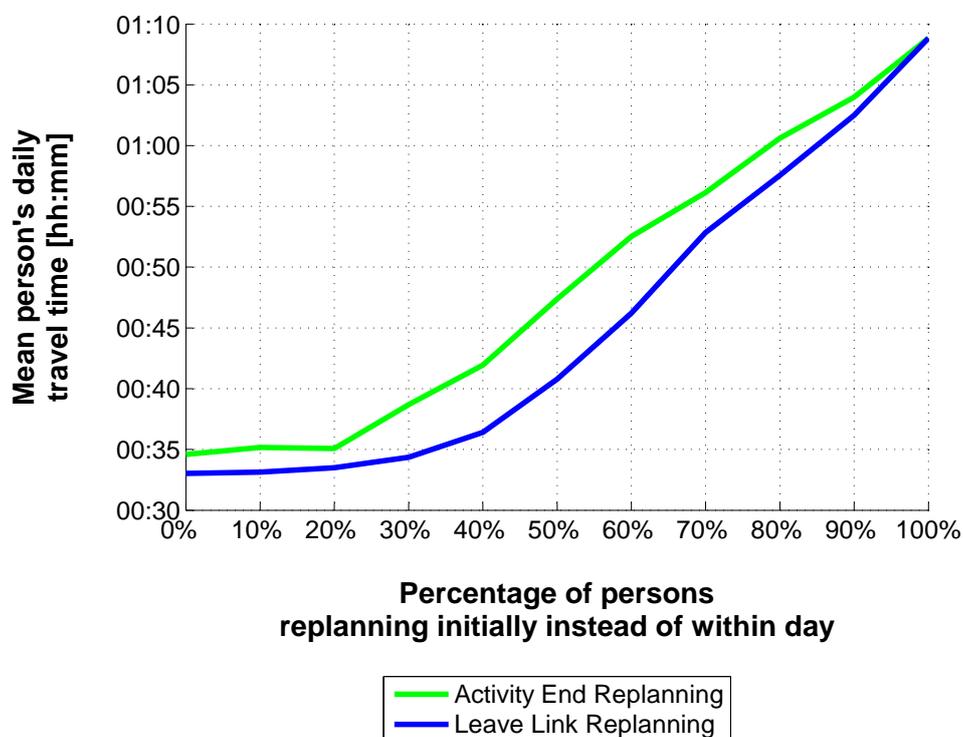
As the results in figure 7 show, it is not necessary that every person uses a router that respects the load of the network. Even if 20% of the people don't use such a router, the remaining 80% are able to keep the system in a steady state with no significant change of the mean travel time of a person per day. Again both within day replanning strategies produce comparable results whereas the Leave Link Replanning Router performs slightly better.

4 Conclusions

Problems in the field of transport planning are typically very complex. The complexity gets even higher if the individuals within a traffic system have different information about the system like its infrastructure or its actual traffic load. This study analyzes the relation between the knowledge of the people and the state of the traffic system they are acting in.

As one would expect the results of the simulations show that persons without a routing strategy that takes the structure of the road network into account are typically not able to find reasonable routes with short travel times. If a router that has information about the network structure is used the mean travel time per person and day is reduced significantly. Even better results can be achieved if additional information about the load of the links within the network is available and respected by the routing algorithm.

Another result is that it is not necessary that the people know the entire network and its state. Depending on the traffic in the network even a very limited amount of knowledge can be enough to keep the system in a steady state where no further significant improvements of the traffic situation are possible.

An interesting detail that should be analyzed further is that in the simulated scenario the usage of within day replanning strategies that respect the actual load of the network seems to be able to stabilize the equilibrium of the traffic system. Even if a certain number of people within the system use an initial replanning strategy - what typically causes more traffic and slower routes - the mean travel time per person stays almost constant.

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