Dynamic Routing Using Maximal Road Capacity

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Abstract: Current routing devices route an individual car driver from start to destination in the shortest time. In this paper we propose a routing algorithm, routing the whole population of car drivers in the shortest time. The algorithm is an adapted dynamic version of the shortest path algorithm of Dijkstra, taking care of current and future changing traffic loads on the highways. To use the maximal road capacity car drivers will be routed not only via the shortest individual route but also via routes with a small variation in traveling time. The algorithm has been tested in real life and simulation studies using a historic dataset of tracked cars.

Key words: Dynamic routing, Dijkstra algorithm, Optimisation, Congestions, Experiments.

INTRODUCTION

At this moment we observe an increase in mobility and reduced road capacity. There are increasing numbers of traffic jams on the highways in Europa, especially during the rush hours. More and more people live outside the city where they are employed. Huge shopping malls are created outside the cities and resulted in an increase of car mobility. Peak hours start earlier and last longer. As a consequence roads are getting more and more crowded and the traveling time from source to destination is increasing and the predictability of traffic streams is decreasing. How to reduce traffic congestion, especially in and around the cities is the research challenge of this report.

There are two main solutions. A simple solution is to increase the road capacity. But this is in many cases not an option anymore, because of limited budgets, limited space, and negative ecological impacts. Optimal use of the existing infrastructure via traffic information and management and integration of multimodal traffic streams (cars, trains, bikes and other forms of public transport) is an alternative solution.

In this paper we consider the option to reduce traffic jams by using the available road capacity in an optimal way. Some car drivers will be forced or requested to take some longer routes to improve the traveling of the whole cohort of car drivers. Also the Dutch Government wants an optimal use of the road infrastructure at the cost of individual wishes and privileges. Not very car driver has an altruistic attitude but tries to reach his destination as soon as possible not always taking care of other drivers.

At this moment many car drivers use a static routing device routing cars along the shortest route. But this is not always the shortest route in time, especially in the rush hours. Static routers are not able to take into account dynamic changes of the traffic load or to be expected delay because of traffic jams because of incidents. Increasing number of car drivers use dynamic routing devices. Such a routing device takes care of upcoming traffic incidents and even tries to model the future. An individual car driver will be guided along the shortest route from start to destination. Most car drivers use the same or similar routing devices and this implies that many car drivers are advised to take the same shortest route. This will result in a higher density of cars on some roads in the rush hours. In many cases there is not enough free capacity on the roads and traffic jams appear.

If there is a traffic jam the free capacity of the road decreases with more than 14 %. Well-known are the congestion shock-waves caused by a small disturbance. If one driver has to break suddenly other drivers have to break too, resulting in a congestion or even collision. Most car drivers use familiar routes. Alternative routes which are maybe some minutes longer are not considered. One of our research questions is, if it is possible to reduce the traveling time of the cohort of all car drivers using capacity of the road network in an optimal way, maybe at the cost of traveling time of some individual drivers. The proposed solution is that all drivers having a smart phone install a special App. Drivers
Inform the system about the desired destiny and allow the system to track them. At regular times they send their position to a centralised system and in return they get a routing advice how to reach their destiny in shortest time.

**RELATED WORK**

Various shortest path algorithms are available for computing the optimal route. The most popular algorithm is Dijkstra’s algorithm [1] that has a runtime complexity of $O(n^2)$, where $n$ is the number of nodes in the network. Many variations to the Dijkstra’s algorithm such as bidirectional search and binary heap implementation have been proposed to improve its response time. In case of incidents or congestions, the shortest path is usually unequal to the shortest traveling time. To minimize the traveling time a dynamic routing algorithm is needed, which is able to adapt to the dynamic changes that take place in the traffic network. Recently, ant colony optimization was applied to the vehicle routing problems with time-dependent travel times [2,3,4,5,6,7,8].

Dynamic Travel Time estimation requires the computation of the traveling time for each road in the network in order to assign minimum paths to the requests. Nowadays, there are commercially distributed systems which provide an approximation of the traveling time based on current traffic speed and density. The information they use, derives from the measurements achieved along the highways for the traffic flow.

But the prediction in this case is done on the current situation, the future is not taken into account. In this paper the forecast of the travel time is based on historical data. In Figure 1 we display speed and traffic density models for different times of the day. Logging these data for a longer time provides the data needed to predict the traffic speed or flow for different times of the time. Usually different models are used for different seasons, different days of the week, different weather conditions etc.

![Speed and Traffic Density Models](image)

**Figure 1: Time dependent speed and traffic density plots on the highway A4.**

In order to measure traveling time there are various modalities, such as AVI tracking, car plates registration or inductive loop detectors. In The Netherlands the information used in traffic management is mostly obtained from inductive loop detectors (ILD) placed in the pavement of the highways or cameras (see Figure 2). Most commercial routing devices ask permission of car drivers to track them by their mobile phone. At regular times the GPS position of the car is send to a central or distributed service centre. A dynamic routing advice has been computed and sends back to the car driver.
Figure 2: Paired loop detectors wired in the pavement, traffic surveillance cameras.

DYNAMIC DIJKSTRA ALGORITHM

The algorithm uses an annotated graph to represent the street network of a city. The edges correspond with the streets and the nodes with the intersection of the streets. The edges are annotated with the traveling time between neighbouring nodes. Figure 3 shows the graphical display of the algorithm. At each cycle, the algorithm calculates multiple versions of a particular annotated graph. Each graph represents the situation at a particular time $t$. The dynamic changes at $t_i$ onto the graph($t_0$) are represented by creating a copy of the graph($t_0$), i.e. graph($t_i$), and changing the weight of the edges. By this way, we add the time parameter as a new dimension to the original Dijkstra algorithm. The example shows a space graph represented by nodes {A, B, C, D, and E} that is repeated for three time interval $t=[0..2]$ with interval 5 minutes.

We make the following assumptions. Once we are traveling via an edge we cannot stop or return. When we reach a neighbouring node at $t_i$ we can choose a next node considering the adapted traveling time in the graph at plane $t_i$. 
Let us assume that we want to travel from A to D. Using static Dijkstra it proves that at $t_1$ (9.00h) the route A-B-D is the shortest route (all other routes are longer). But in reality after reaching node B at $t_2$ (9.05h) it takes 20 minutes to reach D so the total travel time is 25 minutes.

Using dynamic Dijkstra the path A-B-D takes again 25 minutes, if we travel from A to C it takes 10 minutes and then at $t_3$ it takes 5 minutes to travel from C to D, in total 15 minutes. The final output is the path A-C-D.

**PROBLEM DEFINITION AND PROPOSED SOLUTION**

To explain our problem we consider two routes from two cities in the Netherlands Eindhoven and Amsterdam (see map). The red route is the shortest one and all car drivers are routed along this route by all traffic devices. The blue route is a little bit longer and takes on average 5 minutes longer traveling time. But on an average working day of the week traffic density increases and congestions appear along the red route from 7.30h until 11.00h. The traveling increases up to 20 minutes. The idea is to advice some car drivers to take the blue route from 7.30h on. If we route half of the cars via the red and the other half via the blue route the traveling time along the red route still increases but not as much as before. Maybe some car drivers are advised to take the blue route in still of the preferred red one which results in some increase of the traveling time. But the traveling time for the whole cohort of car drivers decreases up to 10% compared to individual routing and the available capacity of the roads has been used in an optimal way. At this moment information on DRIP panels informs car drivers about the traveling time along different routes. Next future when car navigation systems take care of future developments road capacity the information is compatible with the information on the DRIPS.

**Architecture**

In this section we present an adapted version of our dynamic routing system described in [9, 10, 11, 12]. Car drivers on the road are via their smart phone connected to a central server. At start they send their destination to the central system.
Their actual speed and the density on the roads are measured by road sensors and this data is also transmitted to the central server. Based on this data the speed and density of traffic flow is computed. At regular times every individual car driver sends his GPS location to the central server. This enables the system to track every individual car driver and to provide an individual routing advice.

ANWB is one of the services which attempts to offer a live traffic update for the highways network in The Netherlands. It shows real-life graphical information about the bottlenecks on the highway network by giving an estimate of the current average speeds. This traffic information is available 24 hours a day on their website and is free. The historical data needed to apply the dynamic Dijkstra algorithm was collected from the ANWB website. The traffic data was collected each 10 minutes for a couple of weeks for a roadway network that comprised the highways and a few national roads from the country. For each road the traveling time was extracted from the text files that offered by ANWB.

OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world. OSM follows a similar concept as Wikipedia does, but for maps and other geographical facts. An important fact is that the OSM data does not resume to streets and roads. Anybody can gather location data across the globe from a variety of sources such as recordings from GPS devices, from free satellite imagery or simply from knowing an area very well, for example because they live there. This information then gets uploaded to OSM's central database from where it can be further modified, corrected and enriched by anyone who notices missing facts or errors about the area. OSM creates and provides free geographic data such as street maps to anyone who wants to use them.

On the central server the dynamic augmented routing system is running. It is possible to install the route planner on the smart phone and only the augmented module will run on the central server. But the current prototype is a centralised system.

Experiments

Experiment 1

Our problem in a simplified graph is displayed in Figure 8a, b. Car drivers traveling from 1-10 can choose the shorter southern route or the longer northern route.
Without using our system it can be expected that car drivers take the southern route. If the number of car drivers increases there will be a congestion on the road from 2-6 and sometimes later even on the road 1-2. The speed on the roads 1-2-6 is decreasing and the traveling time will increase. At some moment the traveling time along the southern route will be longer than along the northern route. So it makes sense to advice car drivers to take the northern route at some moment. When there is no congestion on the roads there is no need to route along the northern route but when there is heavy congestion on the southern route we are too late. The crucial parameter is the traveling time \( t_s \) along the southern or \( t_n \) along the northern route. If \( t_s < t_n \) (or even better if \( t_s \) approaches \( t_n \)) then car drivers should be assigned to the southern or northern route randomly. In this way the road capacity will be used maximally and the total traveling time minimal. The remaining question is how to compute the traveling time from source to destination under dynamic changing environments.

In a next experiment we used a simulation of the city of Rotterdam. Car drivers from the south to the North can be routed via different routes. We compared the option when all cars are routed via the shortest route to the option that cars are distributed over all possible routes. It proves again that in the latter option the whole cohort of car drivers is routed faster. The results are very dependent of the traffic loads and the assumption that car drivers are willing to take the advised routes.
Experiment 2

At this moment car drivers are free to choose where to drive. Most routing devices also route individual car drivers to their destination in an optimal way. But along highways on crucial points DRIPS (Dynamic Routing Information Systems) are installed. On such a DRIP information can be displayed. In case of incidents car drivers are warned for upcoming traffic jams. But on some places car drivers are informed to take an alternative because this is shorter or will be shorter in time. In case too many car drivers choose the alternative and the travel time along the alternative is not shorter anymore the information will be switched off. The DRIP information is generated on base of the measurements of traffic speed and density via the wires in the road surface (loop detectors).

Experiment 3

We consider the situation as displayed in Figure 4, 5. Some car drivers are routed via our Augmented Routing system as displayed in Figure 7. These car drivers are advised to take the blue or red route depending of the predicted traveling time. We tracked these car drivers (a set of volunteers) and computed the traveling time for different times of the day.

We consider a graph of the speed along the longest and shortest route (blue and black line). The resulting traveling time of the whole cohort including our volunteers with special routing advice is displayed as a red line between the blue and black line. The results are dependent of the traffic densities and the willingness of the car drivers to follow the routing advice. In this experiment the car drivers were selected to take part in the experiment on a voluntary basis. The best result is the blue line but it is impossible to realise this results
because all the traffic along the black line has to spit up along the blue or black part.

**CONCLUSIONS AND FUTURE WORK**

In this paper we discussed an option to reduce traffic jams and congestions. The basic idea is to route car drivers not only taking care of the wishes of individual car drivers but also taking care of the whole cohort of car drivers. Because of individual freedom of car drivers on the road the only option is to advise them to take alternative routes via DRIPS. But if they insist on their individual, well known routes nothing will change. The alternative route algorithm should be implemented in current routing devices. Unfortunately at this moment dynamic routing systems take only care of individual demands. In this paper we tested our in-house developed dynamic routing system. It proves that if travel time along an alternative route differs significantly from the chosen route, drivers consider the alternative option seriously. Prediction of future developments is taken into account by using historic data. The total travel time of the whole cohort of drivers reduced up to 10%. Information on DRIPS and personal routing devices will be taken seriously by most car drivers.

**REFERENCES**


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