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To cite this article: A A Agafonov and V V Myasnikov 2018 J. Phys.: Conf. Ser. 1096 012029

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Vehicle routing algorithms based on a route reservation approach

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Abstract. Traffic congestion remains a serious problem in transportation networks. Widely used navigation systems can only react to the presence of traffic jams but not to prevent their creation. One of the possibilities to prevent congestion is to manage road traffic within the urban area. This work considers a route reservation approach with possibility to reroute a vehicle during a journey. This approach decomposes road segments into time-spatial slots and for every vehicle it makes the slots reservation for the corresponding route. Since the travel time in real networks cannot be determined precisely and can be considered as stochastic, we propose to use a rerouting procedure to minimize the traveling time. The experiments are carried out in microscopic simulation of a real-world traffic environment in the transportation network of Samara, Russia, using multiagent transport simulation MATSim.

1. Introduction

Traffic congestion problem is one of the most important problems in transportation systems. The growth of traffic level in densely populated areas increases travel time that users spend on the roadways, increases fuel consumption and fuel emissions, and as a result increases frustration experienced by drivers. Traffic congestion often occurs because drivers do not have accurate real-time traffic information and information about future road utilization and therefore prefer to use popular routes instead of possibly longer but non-congested routes.

The optimal routing problem has been the subject of many studies during the past decade [1–3]. Existing formulation of this problem allows to find the shortest path or generate an adaptive route from the origin to the destination in static or time-dependent, deterministic or stochastic transportation networks.

Vehicle routing guidance systems can use actual or predictive traffic information for routing vehicles with the minimal travel time. There are different approaches to the classification of routing guidance systems [4].

A routing problem in static systems is solved under the assumption that the traffic flow characteristics are independent of time. In [1], different shortest path algorithms were tested on roadways for real-world scenarios. Dynamic systems take into account real-time traffic information that allows responding to the changing conditions of the roadways [2,5]. Stochastic route guidance algorithms assume stochastic nature of traffic conditions and travel times for road segments of the network. In this approach, travel time is considered as a random variable [3, 6, 7].

Stochastic systems require large amounts of data and computing resources for route guidance but allow to better react to the stochastic nature of congestions.

Routing guidance systems can also be classified according to the type of information used to determine the path: real-time systems and predictive systems. In [8], the authors compared the effectiveness of various routing strategies in real-time systems based on current conditions of the network. Predictive systems perform vehicle routing based on predicted values of the traffic flow parameters for a future time horizon. Reliable routing problem in a time-dependent stochastic network with the use of real-time and predictive traffic information was considered in [9, 10].

In the reviewed papers, authors performed the routing without taking into account the influence of the route choice on the overall state of the transport network. The main disadvantage of these systems is that they can only react to traffic jams after they have occurred, but do not prevent the creation of unnecessary congestion. The movement of the vehicle on the road segment in a saturation state can lead to the creation of unnecessary congestion on this segment. Therefore, it is necessary not only to minimize the travel time of each vehicle but also to prevent the creation of congestion.

Nowadays, more and more companies develop autonomous vehicles. This fact allows us to consider the minimizing travel time problem in a different point of view: how to balance the traffic load throughout the road network efficiently. Such distribution of the vehicles can reduce the level of traffic congestion, and, as a result, reduce the total travel time in the network.

The paper [11] presented a decentralized approach for anticipatory vehicle routing based on delegate multiagent systems. Each vehicle was represented as an agent that not only chooses a traffic route but also reserves a time slot for the vehicle at an intersection. This information is needed to predict future traffic intensities. The article [12] described the architecture of the system, designed to control traffic in order to prevent traffic congestion. An iterative approach based on the Dijkstra algorithm was presented. In the papers [13,14] authors proposed the vehicle rerouting system to aid drivers in making next road choice to avoid unexpected congestions.

In this paper, we consider a centralized approach for anticipatory vehicle routing. It is assumed that the routing guidance is performed in a centralized traffic management system. We investigate routing algorithms in the deterministic time-dependent transport network, as well as the influence of the rerouting strategies on the total travel time.

The rest of this paper is organized as follows. First, we describe route reservation architecture, introduce basic notations and describe a base routing algorithm. Next, we propose modified routing algorithms with different rerouting strategies. Then, we describe the experimental setup that we use to compare the algorithms and analyze the results of the experiments. Finally, we draw our conclusions and discuss the future work.

2. Route reservation architecture

The objective of the route reservation architecture is to control all vehicle movements over the network and minimize the traveling time. When the vehicle plans to start its trip, it sends a request to the system with an origin-destination pair. Based on the current reserved traffic, the system determines the least cost path for the vehicle with the minimal travel time. It is expected that the vehicle will follow the path provided by the system.

This path is also used to update the reservation state of each road segment at the time the vehicle is expected to traverse the segment. It is unrealistic to expect that all vehicles will move with the predicted speed. Moreover, since the travel time depends on the traffic density on the segment, updating the reservation state of the road segment will change the travel time for all vehicles.

To decrease the travel time deviations, it is proposed to recalculate the path and update the reserved traffic when the vehicle reaches the end of the road segment. Such rerouting procedure is similar to the incremental traffic assignment used in traffic assignment models [15].

The formulation of the routing problem and proposed algorithm are described in the following sections.

3. Problem formulation

We consider the road network as a time-dependent graph G = (V, E), where V is a set of nodes, |V| is a number of nodes, E is a set of edges, |E| is a number of edges. The nodes of the graph correspond to the road junctions, and the edges correspond to the road segments.

Each road segment is characterized by the reserved traffic $r_{ij}(\tau)$, $i \in V, j \in V, e_{ij} \in E$, i.e., the number of vehicles on the road segment $e_{ij} \in E$ at the time τ . Let $t_{ij}(\tau)$ be the travel-time cost of the segment $e_{ij} \in E$ at the time τ .

Let U be a set of vehicles. For each vehicle $u_k \in U$ the origin and the destination nodes are considered known, as well as the start time, i.e., $u_k = (O_k, D_k, \tau_k)$, where O_k is the origin node; D_k is the destination node; τ_k is the start time.

Let $p_k^h = \left\{ e_{O_k, j_1}^h, e_{j_1, j_2}^h, \cdots, e_{j_n, D_k}^h \right\}, e_{ij} \in E$ be the *h*-th path of the *k*-th vehicle between the nodes O_k and D_k .

Earliest arrival time at destination problem

Let $d_i^{h,k}$ be the earliest arrival time of the k-th vehicle at the start of the road segment $e_{ij} \in E$ using the h-th path p_k^h . Given an origin-destination pair (O_k, D_k) , the start time τ_k and the reserved traffic $r_{ij}(\tau), i \in V, j \in V, e_{ij} \in E$, the earliest arrival time of the k-th vehicle to each node of the path can be expressed as follows:

$$\begin{aligned} d_{O_k}^{h,k} &= \tau_k \\ d_{j_1}^{h,k} &= d_{O_k}^{h,k} + t_{j_1,j_2}(d_{O_k}^{h,k}) \\ & \dots \\ d_{D_k}^{h,k} &= d_{j_n}^{h,k} + t_{j_n,D_k}(d_{j_n}^{h,k}) \end{aligned}$$

The routing problem can be expressed as:

$$d_{D_k}^{*,k} = \min_{p_k^h} d_{D_k}^{h,k}.$$

4. Base routing algorithm in a time-dependent network

The shortest path in a time-dependent network is selected based on the current reserved traffic on the road segments.

There are different speed-density relationship models exist that allow calculating the travel time of the road segment based on the traffic density on the segment [16]. In this paper, we use the Greenberg model [17]:

$$v_{ij}(\tau) = v_{ij}^* \log \frac{r_{ij}^*}{r_{ij}(\tau)},$$
$$t_{ij}(\tau) = \frac{|e_{ij}|}{v_{ij}(\tau)}.$$

where v_{ij}^* is a free flow speed on the road segment $e_{ij} \in E$; r_{ij}^* is a maximum density on the road segment $e_{ij} \in E$;

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 $t_{ij}(\tau)$ is a travel time;

 $|e_{ij}|$ is the length of the road segment.

A heuristic solution to the earliest arrival time problem is based on the route reservation approach and uses Fast A^{*} algorithm to calculate the shortest path $p_k(\tau_k)$ [18]. As the cost of the road segment, we use the travel time $t_{ii}(\tau)$.

It is unrealistic to expect that all vehicles will be traveling with the predicted speed. Moreover, since the travel time depends on the traffic density on the segment, updating the reservation state of the road segment will change the travel time for all vehicles.

To decrease the travel time deviations, it is proposed to recalculate the path and update the reservation state using a rerouting procedure. Such approach is similar to the incremental traffic assignment approach used in traffic assignment models. The order of choosing the vehicles $u_k \in U$ is important for the rerouting process. We order the vehicles by the distance to the destination node in ascending (i.e., priority for the short paths) and descending (i.e., priority for the long paths) orders. We also consider rerouting strategy without sorting the set U.

Algorithm 1: Rerouting algorithm

Calculate the shortest paths $p_k, \forall u_k \in U$ and the reserved traffic $r_{ij}(\tau)$; $time_{last} = 0;$ while $U \neq \emptyset$ do if $(time - time_{last}) > \Delta_{time}$ then // Rerouting process Clear the reserved traffic $r_{ij}(\tau) = 0, \forall \tau, e_{ij} \in E;$ Create the ordered by the selected criteria set U_{sort} of currently moving vehicles; for $u_k \in U_{sort}$ do Calculate the shortest path p_k from the current vehicle position to d_k ; for $e_{ij} \in p_k$ do Calculate the enter segment time τ_{in} ; Calculate the leave segment time τ_{out} ; Update the reserved traffic information: $r_{ij}(\tau) = r_{ij}(\tau) + 1, \forall \tau \in [\tau_{in}, \tau_{out});$ end end $time_{last} = time;$ end if u_k reaches the destination then | Remove u_k from U; end end

In the Algorithm 1: time is a current time instant, Δ is a predefined reporting time

 Δ_{time} is a predefined rerouting time interval.

The Algorithm 1 has the following disadvantage: the total travel time in the network depends on the order of choosing the vehicles $u_k \in U$ because there is no user equilibrium in the network. In the next subsection, we present an algorithm based on the iterative process.

5. Routing algorithm with the iterative rerouting process

A pragmatic way to find the time-dependent user equilibrium is by an iterative simulation. This approach is typical for the traffic assignment problem in traffic simulation models [19].

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Algorithm 2: Iterative rerouting algorithm

Calculate the shortest paths $p_k(\tau_k), \forall u_k \in U$ and the reserved traffic $r_{ij}(\tau)$; $time_{last} = 0;$ while $U \neq \emptyset$ do if $(time - time_{last}) > \Delta_{time}$ then // Iterative rerouting process $T_{avg} = 0; T_{avg}^{old} = 0; iter = 0;$ do $T_{avg}^{old}=T_{avg};$ for $u_k \in U$ do Remove the vehicle u_k from the reserved traffic: for $e_{ij} \in p_k$ do Calculate τ_{in} and τ_{out} ; $r_{ij}(\tau) = r_{ij}(\tau) - 1, \forall \tau \in [\tau_{in}, \tau_{out});$ end Recalculate the shortest path p_k using the updated reserved traffic $r_{ij}(\tau)$. Add the vehicle u_k in the reserved traffic: for $e_{ij} \in p_k$ do Calculate τ_{in} and τ_{out} ; $r_{ij}(\tau) = r_{ij}(\tau) + 1, \forall \tau \in [\tau_{in}, \tau_{out});$ end end Calculate T_{avq} ; iter = iter + 1;while $|T_{avg}^{old} - T_{avg}| > \Delta_{avg} \&\& iter \leq iter_{max};$ $time_{last} = time;$ end if u_k reaches the destination then Remove u_k from U; end end

In the Algorithm 2: time is a current time instant; Δ_{time} is a predefined rerouting time interval; T_{avg} is an average travel time calculated by all the shortest paths p_k ; Δ_{avg} is a maximum delta of the travel times; $iter_{max}$ is a maximum iteration number.

6. Routing algorithm with the rerouting process for each vehicle

Previously described algorithms recalculate the routes for all vehicles on path simultaneously during the rerouting process. Another simple solution to the rerouting problem is to calculate paths and update the reserved traffic information for each vehicle separately. This procedure can be performed at the moment when the vehicle leaves the segment (Algorithm 3).

The proposed routing algorithm consists of the following steps:

1) When the vehicle starts its journey, the system calculates the path used Fast A* shortest path algorithm in a time-dependent network. The Greenberg speed-density model is used to calculate the travel time of the road segment based on the reserved traffic.

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Algorithm 3: Rerouting algorithm for each vehicle

Calculate the shortest paths $p_k, \forall u_k \in U$ and the reserved traffic $r_{ij}(\tau)$; while $U \neq \emptyset$ do if u_k leave the segment then // Rerouting process Remove the vehicle u_k from the reserved traffic: for $e_{ij} \in p_k$ do Calculate τ_{in} and τ_{out} ; $r_{ij}(\tau) = r_{ij}(\tau) - 1, \forall \tau \in [\tau_{in}, \tau_{out});$ end Recalculate the shortest path p_k using the updated reserved traffic $r_{ij}(\tau)$. Add the vehicle u_k in the reserved traffic: for $e_{ij} \in p_k$ do Calculate τ_{in} and τ_{out} ; $r_{ij}(\tau) = r_{ij}(\tau) + 1, \forall \tau \in [\tau_{in}, \tau_{out});$ end end if u_k reaches the destination then | Remove u_k from U; end end

- 2) The reserved traffic state is updated using the determined path and predicted earliest arrival time at each node of the path.
- 3) When the vehicle reaches the end node of the segment, the system recalculates the path from the current node to the destination and updates the reserved traffic.

In the next section, we present the experimental study of the described algorithms.

7. Simulation setup and results

The proposed algorithms were tested using traffic simulation software. The MATSim simulator [20] was selected for our experiments. MATSim is an open-source framework designed to implement large-scale agent-based transport simulations. MATSim supports several microscopic transport simulation models. In this work, we use queue-based model QSim [19].

The proposed algorithms were tested on the transport network of Samara, Russia. The network consists of 7451 nodes and 18586 segments.

The experiment consists of the following steps:

- 1. The origin-destination pairs and the start time were generated for 40 thousand vehicles $u_k \in U$.
- 2. The shortest paths and the average travel time were calculated by the routing algorithms 1-3 described in the sections 4-6.
- 3. The movement of the vehicles along the calculated paths was simulated using the MATSim framework; the average travel time was calculated.

We repeat each experiment by varying the load factor of the network. The load factor determines the proportion of traffic density used in the simulation relative to the traffic density in the real network. For example, if 10% of the vehicles are modeled in the system, then the load factor of the road network is assumed to be 0.1.

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Figure 1 illustrates an example of the traffic simulation in the Samara network using the MATSim framework.



Figure 1. Simulation example.

Table 1 and Figure 2 provides the average travel time (in seconds) calculated by the MATSim simulation framework for the different load factor values.

	0.15	0.2	0.25	0.3	0.35
Algorithm 1 without sorting	3052.2	2797.1	2378.5	23154	2253.3
Algorithm 1 with "short first" strategy	2931.8	2724.5	2363.4	2308.7	2251.7
Algorithm 1 with "long first" strategy	3076.6	2801.9	2402.4	2347.5	2272.2
Algorithm 2	2970.4	2698.6	2334.4	2296.9	2247.2
Algorithm 3	3012.9	2639.9	2318.6	2282.3	2230.4

Table 1. The average travel time values.

The proposed algorithm with the rerouting procedure for each vehicle (Algorithm 3) showed the best results by the average travel time criteria.

8. Conclusion

In this work, we have proposed the routing algorithms in the time-dependent road networks. We have investigated the impact of the rerouting procedure and the iterative rerouting procedure on the average travel time in the Samara transportation network. The routing algorithm with the rerouting procedure and "priority for short routes" strategy and the algorithm with the rerouting procedure for each vehicle have shown the best results by the average travel time criteria.

The main disadvantage of the proposed algorithms is the fact, that the travel time of the each road segment for the different vehicles is equal. In real networks different vehicles on the one road segment can move with the different speed depending on the traffic load on the road segments including in their routes. Further research includes the design of routing algorithms that can tackle this problem.

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IOP Conf. Series: Journal of Physics: Conf. Series 1096 (2018) 012029

doi:10.1088/1742-6596/1096/1/012029



Figure 2. The average travel time values.

9. References

[1] Zhan F 1997 Three fastest shortest path algorithms on real road network: data

structure and procedures Journal of geographic information and decision analysis 1 69-82

[2] Fu L 2001 An adaptive routing algorithm for in-vehicle route guidance systems with real-time information *Transportation Research Part B: Methodological* **35** 749-765

[3] Samaranayake S, Blandin S and Bayen A 2012 A tractable class of algorithms for reliable routing in stochastic networks *Transportation Research Part C: Emerging Technologies* **20** 199-217

[4] Schmitt E and Jula H 2006 Vehicle route guidance systems: Classification and comparison Proceedings IEEE Conference on Intelligent Transportation Systems, ITSC 242-247

[5] Hall R W 1986 Fastets path through a network with random time-dependent travel times *Transportation Science* **20** 182-188

[6] Gao S and Chabini I 2006 Optimal routing policy problems in stochastic timedependent networks *Transportation Research Part B: Methodological* **40** 93-122

[7] Wu X and Marco Nie Y 2011 Modeling heterogeneous risk-taking behavior in route choice: A stochastic dominance approach *Transportation Research Part A: Policy and Practice* **45** 896-915

[8] Wang Y, Papageorgiou M and Messmer A 2003 Predictive feedback routing control strategy for freeway network traffic *Transportation Research Record* 62-73

[9] Agafonov A and Myasnikov V 2016 Reliable routing in stochastic time-dependent network with the use of actual and forecast information of the traffic flows *Proceedings IEEE Intelligent Vehicles Symposium* 1168-1172

[10] Agafonov A and Myasnikov V 2016 Method for the reliable shortest path search in time-dependent stochastic networks and its application to gis-based traffic control *Computer Optics* **40** 275-283

[11] Claes R, Holvoet T and Weyns D 2011 A decentralized approach for anticipatory vehicle routing using delegate multiagent systems *IEEE Transactions on Intelligent Transportation Systems* **12** 364-373

[12] Menelaou C, Kolios P, Timotheou S and Panayiotou C 2015 Congestion free vehicle scheduling using a route reservation strategy *Proceedings IEEE Conference on Intelligent Transportation Systems*, *ITSC* 2103-2108

[13] Wang S, Djahel S and McManis J 2014 A multi-agent based vehicles re-routing system for unexpected traffic congestion *avoidance* 17th IEEE International Conference on Intelligent Transportation Systems, ITSC 2541-2548

[14] Wang S, Djahel S, Zhang Z and McManis J 2016 Next road rerouting: A multiagent system for mitigating unexpected urban traffic congestion *IEEE Transactions on Intelligent Transportation Systems* **17** 2888-2899

[15] Saw K, Katti B and Joshi G 2016 Literature review of traffic assignment: Static and dynamic International Journal of Transportation Engineering **2** 339-347

[16] Wang H, Li J, Chen Q and Ni D 2009 Speed-density relationship: from deterministic to stochastic *The 88th Transportation Research Board (TRB) Annual Meeting* 1-20

[17] Greenberg H 1959 An analysis of traffic flow Operation Research 7 79-85

[18] Lefebvre N and Balmer M 2007 Fast shortest path computation in time-dependent traffic network *The 7th Swiss Transport Research Conference (STRC)*

[19] Gawron C 1998 An iterative algorithm to determine the dynamic user equilibrium in a traffic simulation model International Journal of Modern Physics C $\mathbf{9}$ 393-407

[20] MATSim 2017 (Access mode: http://matsim.org)

Acknowledgments

This work was supported by the Russian Foundation for Basic Research (RFBR) grant 18-07-00605 A, grant 18-29-03135 and by the Federal Agency of scientific organization (Agreement 007-GZ/43363/26).