Identifying the optimal road closure with simulation

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ABSTRACT

A transportation authority needs to decide which section of a road should be closed to allow road works. There are often multiple ways to close a section of a road, and the way to close the section can have a significant impact on the traffic flows around the closed section. We use IBM Mega Traffic Simulator version 2 (Megaffic2), an agent-based simulator of traffic flows, to analyze the impact of a road closure on traffic flows for multiple ways of road closures. Our analysis gives insights as to how a section of a road should be closed for road works that are planned in Hiroshima city in Japan.

Keywords: Simulation, Hiroshima, What-if analysis, Agent-based, Megaffic, Road closure

1. INTRODUCTION

A primary responsibility of a local government is to keep the network of roads functioning. Road works are sometimes needed to repair damaged segments of a road or to maintain the infrastructure under ground. The benefit of the road works comes at the expense of the closure of a segment of the road during the road works. Such a road closure can in turn cause inconvenience and frustration for the residents around the closed section or for the drivers of vehicles who would otherwise travel through that closed segment. Road works are thus planned in a way that such inconvenience and frustration are minimized.

When road works are needed at a segment of a major road having multiple lanes, there often exist multiple alternative approaches of closing some of the lanes and using the remaining lanes for traffic flows. For example, a major road in Hiroshima city in Japan has three lanes in each direction. Road words are planned on this road, during which all of the three lanes on one side must be closed. The three lanes on the other side can be used with multiple approaches. One approach is to use these three lanes as usual. This means that the vehicles that would otherwise take the closed side of the road must take detours. Another approach is to use the unclosed three lanes for traffic flows in both directions. Specifically, one of these three lanes is used for the traffic flow towards the north, another lane is used for the one towards the south, and the middle lane is closed to create space between the two traffic flows for safety. This allows vehicles to travel in both directions even during road works, but unfortunately the capacity of this segment of the road is significantly reduced. Only two lanes are used with this second approach, while three lanes are used with the first approach.

The difficulty in selecting an appropriate approach to such a road closure is in understanding the traffic flows under the alternative approaches and comparing them to each other. Because the only differences between these alternative approaches are in how the lanes are used, we need a traffic simulator with a microscopic model that can capture such minute differences. In addition, because the traffic flows along a major road such as the one in Hiroshima city consist primarily of the vehicles that travel long distances, one needs to simulate the traffic flows in a large area to precisely understand the impact of a closure of a segment of that major road. Scalability is, however, a major challenge for simulation with microscopic models.

To analyze the traffic flows before and after a road closure in detail, we have developed IBM Mega Traffic Simulator version 2 (Megaffic2) [13,14], an agent-based simulator of traffic flows that allows massively parallel simulation of individual vehicles whose movement is governed by behavioral models that are estimated based on probe-car data [15]. We use Megaffic2 to evaluate the impact of the closure of the one side of the major road in Hiroshima city under each of the two approaches of using the unclosed lanes on the other side of the road, which constitutes the primary contribution of this paper. We discuss how the results of the simulation are used to help the transportation authority select an appropriate approach to the road closure.

2. SETTINGS OF SIMULATION

We consider the scenario of road works that forces the closure of one side of the Gion Shindo road. Specifically, all of the three lanes in the direction towards the north are closed from the intersection of Johoku Eki Kita to the intersection of Hakushima Eki Kita. The road works are planned for five hours from the midnight to 5:00 am. We will simulate traffic flows in three settings (see Figure 1). The first setting is the baseline without any road closure when road works are not performed. The three lanes on one side towards the north are closed in the remaining two settings. The second setting uses the remaining unclosed lanes only for vehicles towards the south. The third setting uses one of the unclosed lanes for vehicles towards the north and another unclosed lane for those towards the south; the middle lane is closed to create space between the two traffic flows.

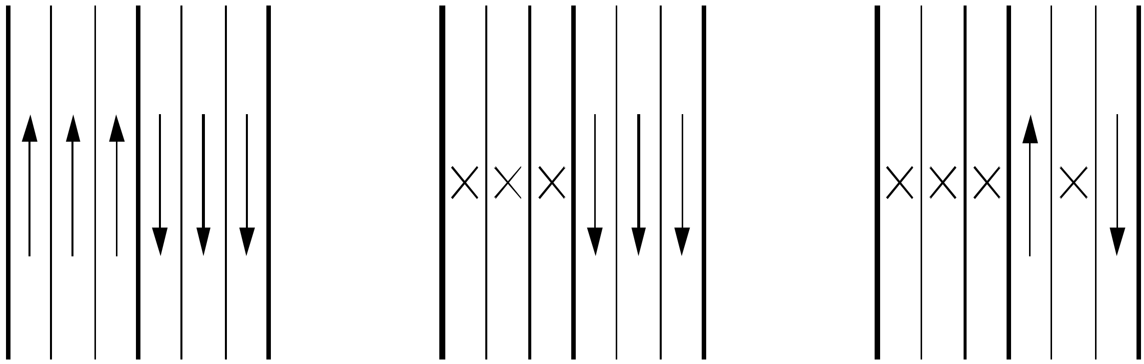


Figure 1. The baseline (a) and two settings of road closures (b,c).

To compare the traffic flows under the three settings with each other, we simulate these traffic flows in a square region that contains the entire Hiroshima city. We obtain the data of the network of roads in this region from OpenStreetMap (https://www.openstreetmap.org/). More specifically, the simulated region contains the latitude from 34.296721 to 34.615621 degrees North and the longitude from 132.17887 to 132.69629 degrees East. There are about 232,000 intersections and 500,000 road segments in this region. For the two settings of the road closure, the road network is manually modified accordingly.

To simulate the traffic flows for the five hours during the road works, we start from empty traffic and simulate the traffic flows for ten hours but ignore the first five hours. We generate trips based on the results of survey from the fiscal year of 2005. The results of survey imply the number of trips of vehicles from a zone to another for 24 hours for each ordered pair of zones, where Hiroshima city is divided into 220 zones. The survey also includes the trips that start or terminate in the zones outside Hiroshima city, and there are 72 such zones. The number of trips for 24 hours is reduced by a factor of 0.27 to obtain the number of trips for 12 hours of night (7:00 pm to 7:00 am), and this number is further reduced by a factor of 10/12 to obtain the number of trips during the ten hours to be simulated. For each trip, the origin is selected uniformly at random from the intersections in the zone where the trip starts, and the destination is selected analogously. The selection of the origin and the destination can be made more realistic when probe-car data is available [11]. The departure time is selected uniformly at random from the ten hours at the granularity of seconds. We ignore the trips whose origin or destination is out of the simulated region.

The behavior of vehicles, including how they select their routes and speeds, are determined by Megaffic2 [13,14]. In particular, the route of each vehicle is selected in two approaches: *drivers without personalities* and *drivers with personalities*. The first approach of *drivers without personalities* chooses the one with the shortest travel time. The second approach of *drivers with personalities* chooses the one having the minimum weighted average of three quantities: travel time, travel distance, and the number of turns. Here, the weight for each vehicle is sampled independently according to the distribution that is estimated from the probe-car data of taxis in the greater Tokyo area (see [14] for more details). In both approaches, the travel time is updated every 10 simulated minutes to reflect the latest simulated traffic conditions. Throughout, each vehicle changes its speed according to the car-following model of Gipps [4] and changes the lanes according to the model of Toledo et al. [20]. The maximum speed and the number of lanes are set as shown in Table 1.

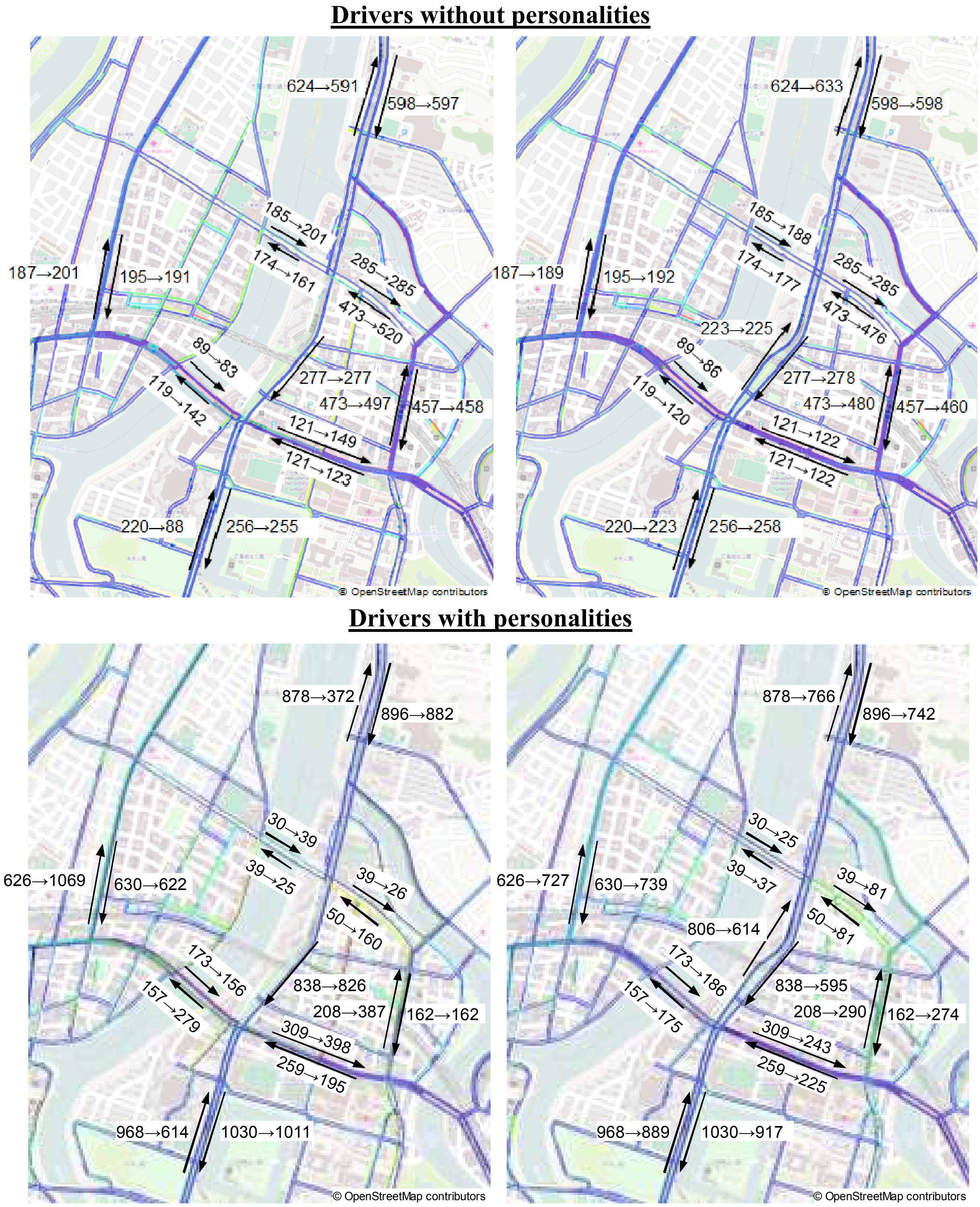
Road type	Maximum speed	Number of lanes
motorway	100	3
trunk	70	3
primary, motorway_link	60	1
secondary, trunk_link	50	1
tertiary, primary_link, unclassified, road	40	1
residential, secondary_link, tertiary_link	30	1
living_street	20	1

Table 1. The maximum speed (km/h) and the number of lanes set for each type of a road.

3. RESULTS OF SIMULATION

Figure 2 shows some of the results of simulation. Here we evaluate the traffic volume (i.e. the number of vehicles per hour) along each road segment in the second setting (left figure) and in the third setting (right figure). The colored segment denotes the traffic volume relative to the corresponding value in the first setting (i.e. no road closure). For example, a blue segment denotes that the traffic volume is unchanged, and a green segment denotes that the traffic volume is doubled. Minor roads are not colored. The change in the absolute traffic volume is labeled along key road segments, where the road closure can have a significant impact on traffic flows.

In Figure 2, the top row shows the results of simulation using drivers without personalities, and the bottom row using drivers with personalities. Observe the significant differences in the absolute traffic volumes between the two cases. This difference suggests the importance of how to set the personality of each driver (i.e., the weight for each metric of the cost such as travel time, travel distance, and the number of turns). See [15] for an approach to systematically estimating the personality.



(a) South only **(b) Both directions**

Figure 2. The left figure (a) shows the changes in the traffic volume when all of the lanes on one side are closed, and the other side is used as usual. The right figure (b) shows the changes when all of the lanes on one side are closed, and two of the three lanes on the other side are used to flow traffic in both directions.

We can observe nontrivial increase in the traffic volume alone detours as well as a significant reduction of the traffic volume along the Gion Shindo road, where the road works are performed. After carefully examining these and other results of simulation with the persons in charge of transportation in Hiroshima city, we conclude that the impact of the road closure on the traffic flows is acceptable with either of the two approaches of using unclosed lanes. The transportation authority can thus choose either of these two approaches by taking into account only the other factors such as safety and cost. A significance of our study is that it removes the concern of the transportation authority about traffic congestion with the confidence that is supported by the quantitative study with simulation.

4. RELATED WORK

Traffic simulation has been studied extensively in the literature [1,5]. Various traffic simulators have been developed and applied to planning, controlling [18], and forecasting [9] traffic systems or to study the fundamental characteristics of traffic flows [6]. Traffic simulators range from microscopic to macroscopic [12, 8]. An agent-based traffic simulator such as Megaffic2 [13,14] is a representative microscopic simulator that tracks the location, the speed, and other states of individual vehicles at every time step. A macroscopic traffic simulator tracks the features of traffic flows rather than individual vehicles.

The prior work has evaluated the impact of road (or lane) closures with traffic simulation with microscopic simulation [7], mesoscopic simulation [2], or macroscopic simulation [3]. Road closures have also been considered, when the impact of natural disasters are evaluated with simulation [22] or when near-term forecast of traffic conditions are made with simulation [10].

5. CONCLUSION

We have quantitatively evaluated two approaches to closing a section of a major road in Hiroshima, using Megaffic2, an agent-based simulator of traffic flows. Hiroshima city plans to adopt one of these two approaches to enable road works along that major road. Although the road works are planned during the night when the traffic demand is relatively low, there is a concern about unacceptable congestion along detours. The results of our simulation suggest that the traffic volume and the driving speed are acceptable with either of the two approaches under consideration. Hiroshima city can thus make a decision as to which approach should be adopted solely based on safety, cost, and other factors, without worrying about traffic congestion.

Our experience of the collaborative work with Hiroshima city suggests that traffic simulation can be useful in helping the decision making of transportation authorities. Today, traffic simulation is not a standard tool for transportation authorities. They make decisions, relying on their intuitions that are supported by their experiences. Unfortunately, human decisions are susceptible to cognitive biases and, as a result, systematically irrational [16]. It is thus of paramount importance to support such humans' decisions with scientifically grounded tools.

Today's traffic simulators still need improvement in their reliability of the results of simulation. Our study suggests that the results of simulation significantly depend on the personalities of the drivers (i.e., the weight for travel time, travel distance, and the number of turns). In most of the existing traffic simulators, the driver of a vehicle takes the route having the shortest travel time, ignoring other factors such as travel distance, turns, cost, the width of roads, traffic signals, and the risk of congestion. Other simulators take into account multiple metrics (e.g., time and cost), but the weight is fixed for all drivers. On the other hand, real drivers are heterogeneous [18,20,22].

A promising approach for improving the reliability of traffic simulators is to effectively utilize probe-car data, the trajectories of the drivers measured by the Global Positioning System (GPS). The probe-car data result from the behavior of the drivers and thus contain rich information that can be exploited for building realistic behavioral models of the drivers. An instance of the use of the probe-car data is in the *drivers with personalities* that we have used in our study. Because we use a limited amount of the probe-car data, the results of the simulation using our *drivers with personalities* are not always reliable. Our expectation is that effective use of “big” probe-car data will allow us to realize traffic simulators that are sufficiently reliable for transportation authorities.

6. ACKNOWLEDGMENT

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