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Multi-Agent Approach Traffic Forecast for Planning Urban Road Infrastructure

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***Abstract*—In Joensuu, Finland, a new bridge, *Sirkkalansilta*, was to be built. In this work, we study its effect on the working population's commuting traffic. We investigate, with the working population census data, the traffic flow conditions of without and with the new bridge using multi-agent traffic simulation. We also investigate the correlations of the bridges with regards to bridge closures. Actual hourly bridge usage data was collected by Joensuu city council after *Sirkkalansilta* was opened to traffic. We compare our simulation with the collected hourly bridge usage data to conclude on the feasibility of using multi-agent traffic simulations for real world application and propose how it can provide suggestions on future improvement.**

I. Introduction

Priori data is not always available. In many cases, it is easier to simulate data through generating random processes of the situation intended [1]. Other ways of simulating data targeting different situations such as *Watkins et al* demonstrated genetic algorithms can be used to generate data for human movement in Ecological Modeling [2]. Simulating traffic data is helpful in road infrastructure planning for growing cities. Studies have shown daily urban traffic conditions can be predictable [3]. However, unpredictable situations such as accidents and weather can still alter the traffic flow; impacting everyday productivity. In Joensuu, a new bridge, Sirkkalansilta, was to be built. We would investigate Sirkkalansilta's traffic flow and the correlations of it with the other bridges.

In this paper, using *multi-agent system* (MAS) to demonstrate likely impact of a new bridge built in Joensuu on the cars traveling behavior is studied. The MAS environment simulated is the road network systems of Joensuu and its surrounds. The agents interacting in the road-network systems are cars that uses it daily. The cars are modeled after the data that was provided by the Joensuu municipal office. The data consist of timings of people leaving for work in the morning and home in the evening. The usage and correlations of the new and present bridges are investigated in the simulation. As Sirkkalansilta was opened for traffic, real-world bridge data was collected by Joensuu municipal office. We used the data to verify if MAS is a feasible for urban infrastructure planning.

II. Methodology

Joensuu municipal office has offered its population census and their occupation's workplaces for this study. Joensuu is a university city. It is the second largest city in Eastern Finland with a population of 75,652. The campus of the University of Eastern Finland is part of Joensuu. The Pielisjoki river separates the city. From the data, Joensuu has a population that travels to the town center for work. The people in this data mostly stay in Joensuu's western suburbs with some in North and Northeastern. Most of them will go to work across the river in Mäntylä, Penttilä and Niinivaara. Fig. 1 shows the

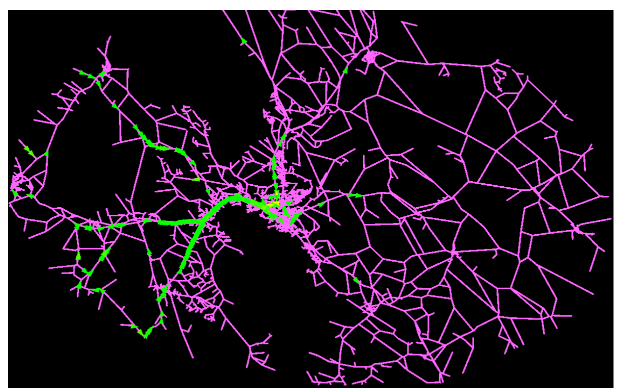


Fig. 1: People traveling to work at 5:30 in the morning

people moving from the western suburbs to their workplaces at 5:30. Workplaces of this group of people shown in Fig. 2 is concentrated in Joensuu City. In Joensuu it concentrates in the city center and across the Pielisjoki river in Mäntylä and Niinivaara shown in Fig. 3.

MAS has been widely used in traffics congestion and flow studies [4]. With the useful inputs to the agents in the simulation, it can even be used to forecast yet-to-be implemented real-life scenarios such autonomous car-to-car systems [5]. For our studies, we used our previous method of deriving travelings schedule to generate one for Joensuu's commuting population [6]. Our method has closely simulated how Singaporean drivers used their roads for daily activities

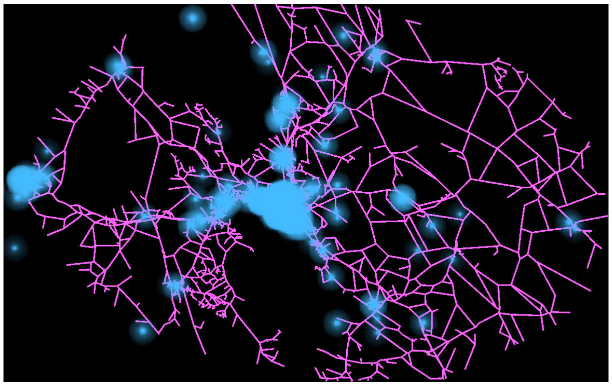


Fig. 2: People at their work activity places at 12:00

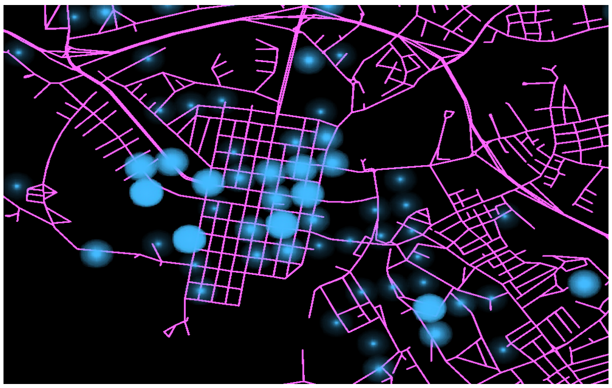


Fig. 3: Concentration of work activity in Joensuu City Center

such as work, school, leisure and etc. We applied the generated schedule to model the scenario that we want to investigate and ran the simulation traffic flow data.

There are many traffic simulators available like *Simulation of Urban Mobility* (SuMO) [7], VISSIM [9] and SimTraffic [8]. They are able to create detailed intelligence in agents and attributes in environment. The agent's intelligence can be as fine as waiting for a number of vehicles to pass before changing lanes on the road. The road attributes can be as fine as a per car lane level. This allows for simulation of an area of a few junctions easily but will be very tedious to build the road network system of an entire city. Each has its strengths in traffic simulation. They can be summarized below:

- **Microscopic control** - able to define how agents in the simulation will behave
- **Macroscopic analysis** - able to monitor and collect data of the affected environment by the agents in the simulation
- **Ease of simulation creation** - simulation is made quickly and without much difficulties. Changes can easily be done
- **Large scale analysis** - able to handle many agents without compromise to computational time and data quality

These criteria were considered because the focus needs to be placed on the simulation and ease of information retrieval. Simulators that save time in getting the simulation to run are given preference. We have tried all the simulators mentioned above and based on our experience Table I shows which traffic simulator is able to fulfill the above criteria.

TABLE I: Comparison of Traffic Simulators: MATSim, SuMO, VISSIM, SimTraffic

Simulator	Microscopic control	Macroscopic analysis	Ease of simulation creation	Large scale analysis
MATSim	YES	YES	YES	YES
SuMO	YES	X	X	YES
VISSUM	YES	X	X	X
SimTraffic	YES	X	YES	X

For simulating Joensuu's likely traffic situation, we chose MATSim [10]. MATSim allows microscopic intelligence control on the agents. Joensuu's road network system is easily imported via *extensible markup language* (XML) format exported from a global mapping application called OpenStreetMap [11].

This simulation objectives are:

- Distribution of traffic flows on the bridges if any of them was to become closed for repairs or other circumstances
- Co-relation of the bridges in terms of traffic flow

When this simulation was conducted, Sirkkalansilta wasn't present on OpenStreetMap. It was manually added by connecting the landing points that Sirkkalansilta was intended to span across. The lane information was not available. It was presumed to be the equivalent lane and car space on each end of the landing points. The same traveling schedule generated from Joensuu's working population data is used for both road systems; without and with Sirkkalansilta shown in Fig. 4 circled in red.

III. Results, Correlations and Comparison

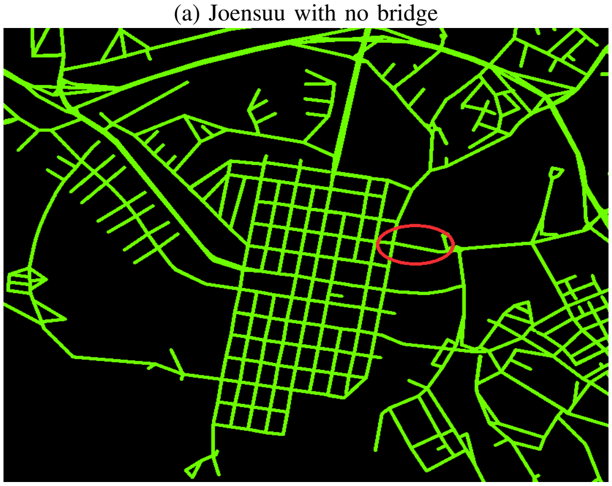
After Sirkkalansilta was opened, Joensuu municipal office tracked its traffic flow as well as Suvantosilta's and Itäsilta's. We compared that data to our simulation results for validation.

A. Results

Two sets of simulations were executed. The first set simulation used the road network system map of Joensuu without *Sirkkalansilta*, whereas the second set included it. As the generated schedule was based on the regular daytime working population, the simulation showed traffic actions in two separate time-slots; morning between 06:00 to 11:00 and evening between 16:00 to 19:00. However, in the simulation where *Sirkkalansilta* has not been built, the last crossing from the east to the west banks of the Pielisjoki river occurred in the hours of 19:00 to 20:00.

From observing both simulations, the bridge is used mainly by people staying in the west to cross the Pielisjoki river from Joensuu town center to work in Mäntylä and Niinivaara in the morning. Shown in Fig. 5 they will cross it again to return to their homes in the west in the evening. There are three routes to cross the Pielisjoki as shown in Fig. 6. In using Suvantosilta and Itäsilta, drivers detoured into town. Before the

(a) Joensuu with no bridge



(b) Joensuu with added bridge

Fig. 4: Joensuu's city road network before and after the newly built bridge

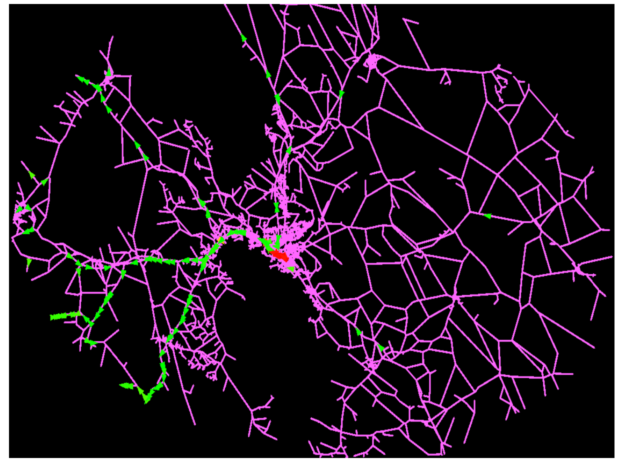


Fig. 5: People returning to their homes at 17:00 in the evening

Fig. 6: Three former options to cross over Pielisjoki river from Joensuu and Sirkkalansilta added as a new and shorter direct route

completion of Sirkkalansilta, drivers either cross the Pielisjoki from Joensuu town center via Suvantosilta or Itäsilta in Fig 6. In reality, Itäsilta is not preferred as a detour is required to bypass the train station after crossing the river in order to reach Mäntylä and Niinivaara. There are more traffic junctions to stop at too if using Itäsilta. Fig. 7 shows the usage of all three routes in the morning and Fig. 8 for the evening before and after the completion of Sirkkalansilta.

There is significant traffic usage on Sirkkalansilta after its completion. Itäsilta, Suvantosilta and Sirkkalansilta crossings peak at 8:00 as commuters are arriving for the start of their work day. Another observations is the number of cars on the other three routes has been significantly reduced for both the morning and evening traffic; notably after Sirkkalansilta is available the number of cars crossing from the east bank of the Pielisjoki to the west completes before 19:00 as shown in Fig. 8. Previously, as shown in the same Fig. 8 the number of cars will only complete the crossing after 19:00. This is due to the roads in Joensuu town center being congested and unable to clear the traffic fast enough in the hours before 19:00 as shown in Fig. 9. Therefore, the benefits of Sirkkalansilta are obvious, the usage by cars is significant and it has also shown that drivers crossed the river in shorter period of time than previously.

B. Correlations

We simulated scenarios where other bridges were non-operational. We wanted to study their impacts on the other bridges. In each study and simulation, we removed one bridge while keeping the rest. By grouping the usages according to bridges, the effects can be seen. In Fig. 10 for Pekkalansilta, its traffic volume is not greatly affected by the removal of Suvantosilta or Itäsilta separately. For Sirkkalansilta, the traffic flow that was previously handled by the absent bridges are transferred to it. For Suvantosilta, traffic flow increases in the absence of other bridges. This increase is big because most of the traffic is handled by Itäsilta and Suvantosilta. Hence, removal of either bridges will cause significant redistribution burden on the others. For Itäsilta, removal of either Perkkalan-

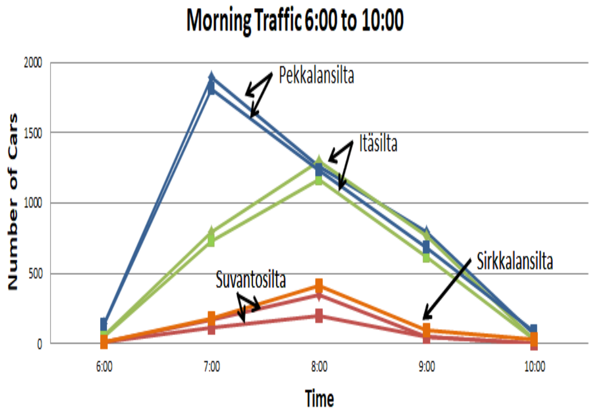


Fig. 7: Comparison of bridge usage in the morning hours. Lines with diamond markers indicate data before bridge was built while lines with square markers indicate after. Lines with the same color mean they are the same bridges.

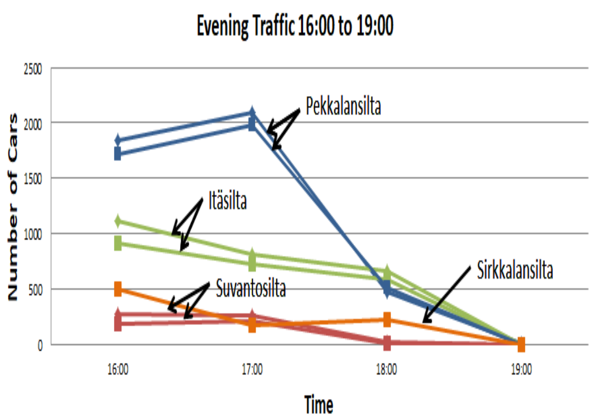


Fig. 8: Comparison of bridge usage in the evening hours. Lines with diamond markers indicate data before bridge was built while lines with square markers indicate after. Lines with the same color mean they are the same bridges.

silta or Suvantosilta causes the traffic flow to significantly decrease. The reason for this still unknown and requires more research work.

In the evening similar behaviors are observed as shown in Fig. 12. We showed Fig. 12 here only because the evening graphs similar to Fig. 10 would not show the comparisons. For Pekkalansilta, the absence of any bridge is negligible. Only the absence of Pekkalansilta significantly affects the traffic flow of Sirkkalansilta. The absences of any bridge also significantly increases the traffic flow on Suvantosilta. Again, the traffic flow on Itäsilta is again interesting; only the absence of Suvantosilta will increase its flow after 18:00. This could be due to people wanting to pass through the town center from the south of Joensuu and Itäsilta is the next nearest bridge from the river mouth.

Fig. 9: Traffic congestion in Joensuu town center before 19:00. Red triangles indicates cars moving slower speeds compared to the greens

C. Comparison

From Fig. 11, it is seen that the simulated and recorded traffic flow for Suvantosilta and Sirkkalansilta followed the same trend. Pekkalansilta is not shown in Fig. 11 as the recorded data was unavailable. Discrepancies are in the different number of cars for each bridge. The differences means that recorded data, other than for commuting, contained cars that are being utilized for other purposes. There are people coming into town for required services or residents staying closer to Joensuu city traveling outwards for non-working purpose. Work commute alone does not form the main bulk of Joensuu's traffic.

The data for Itäsilta did not show trends that the two other silta showed. The reason was MATSim navigates by shortest time metric and hence was not able to take into account driver preferences. The preference of many drivers seems to be not transiting through the city center even though the total time is shorter using Itäsilta according to MAS simulation. This is clear in Fig. 11 where the recorded data showed Suvantosilta's traffic flow to be greater than Itäsilta's. However, the MAS agents were programmed to always use the shortest time. Hence, there is higher traffic volume on Itäsilta since the time spent is shorter compared to Suvantosilta. It is interesting to observed in the recorded data that Suvantosilta is preferred over Sirkkalansilta in the morning and opposite in the evening.

IV. Conclusion

Simulations results showed that the new Sirkkalansilta bridge reduces both the morning and evening traffic on all other bridges as expected. This corresponds to the observed traffic calculations. This shows that MAS is useful planning tool. The exception is Itäsilta, for which MAS predicts higher relative volume than it has in reality.

We also studied how the traffic flow changes if one of the bridges was removed from the road network. Removing Pekkalansilta would significantly increase traffic on both Sirkkalansilta and Suvantosilta, but surprisingly caused also slight decrease on the use of Itäsilta.

Removing Itäsilta or Suvantosilta, however, would not affect on the use of Pekkalansilta almost at all. Removing Itäsilta

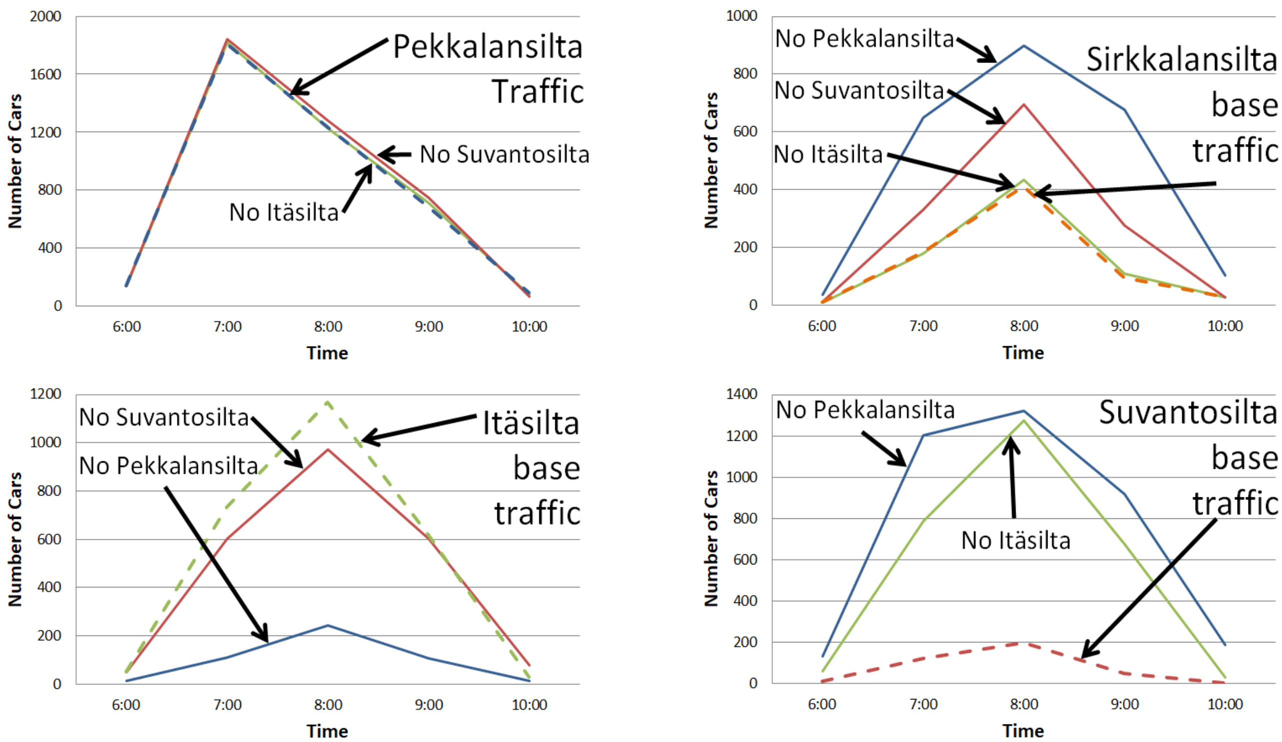


Fig. 10: Morning traffic flow comparison when each bridge is removed from the road network

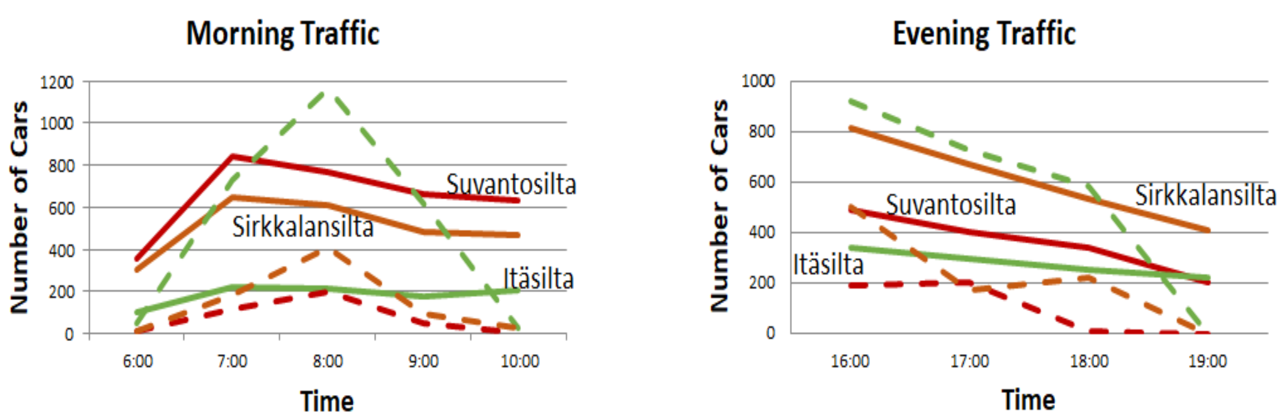


Fig. 11: Simulated and recorded data comparison. Full lines are recorded and dash lines are simulated data. Orange - Itäsilta, Red - Suvantosilta, Green - Sirkkalansilta

would burden the traffic mostly on Suvantosilta, whereas removing Suvantosilta would affect on all other bridges.

The MAS simulation considered only home from/to work commuting but excluded other traffic. This might have some effect on the results.

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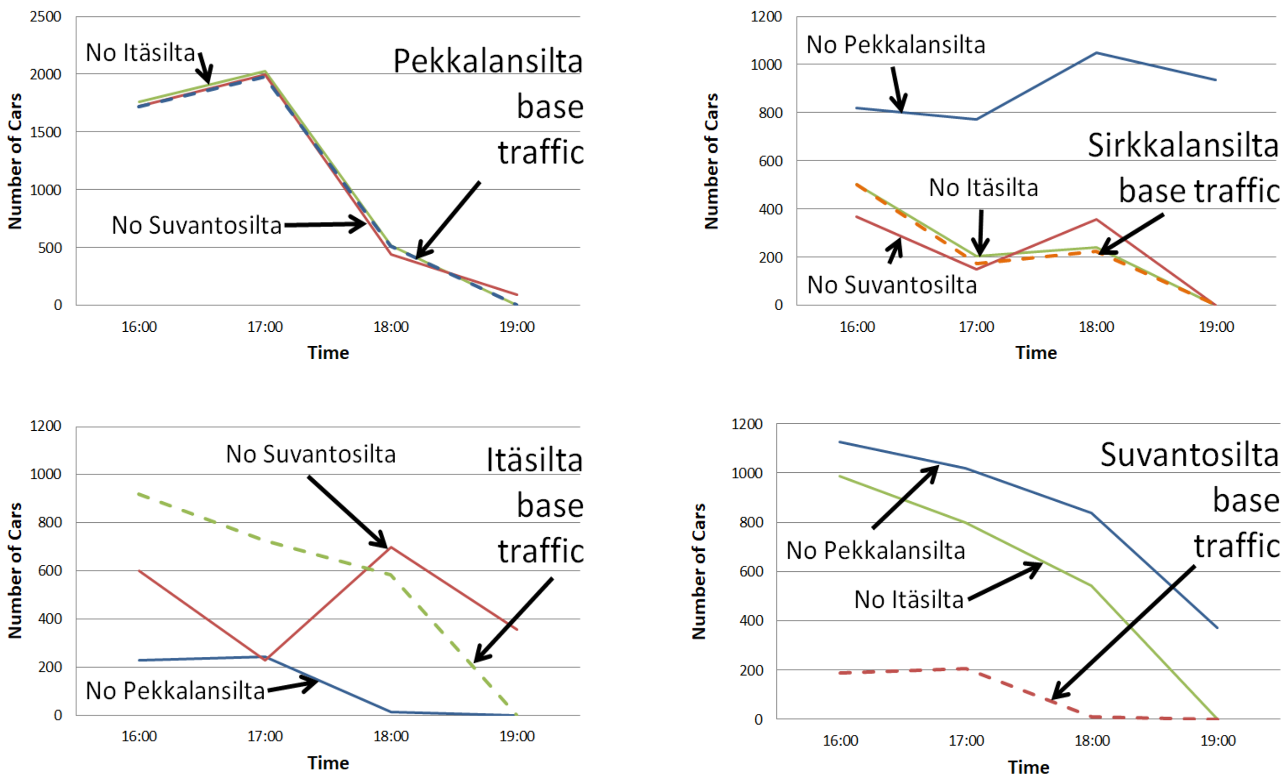

Fig. 12: Evening traffic flow comparison when each bridge is removed from the road network

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