1 The Sioux Falls Scenario

The City of Sioux Falls in South Dakota has been a classical test case in transport research for more than four decades, being first mentioned in this context in Morlok et al. (1973). While none of the numerous implementations of the network are intended to be accurate and realistic with respect to the actual City of Sioux Falls, they are merely aiming towards providing downscaled, computationally tractable test cases for transport planning and simulation problems.

In Chakirov and Fourie (2014) the scenario ("Sioux-14", fig. 1) has been adapted to the MATSim framework. A sparse street network, which is computationally easy to handle by the simulation, was introduced. It consists of 27 nodes and 76 links, representing the main arterial roads of the city, split further down into 282 nodes and 334 links in order to arrive at partial link sizes of less than $500m$. This is necessary, because MATSim agents start their travels at the start node of a link and thus a high resolution is needed to avoid unrealistic clustering. (**TODO** Is it the start node? Or end?)

On the supply side there is furthermore a public transport network, which consists of 5 lines with bus stops along the arterial roads in a distance of $600m$. The stops are placed in a distance of $5m$ perpendicular to the road and departures from the lines' respective start links take place every 5 minutes.

A lot of effort has been put into the modelling of the demand side, covering the realistic generation of home locations, work places, secondary acitivty locations, as well as the distribution of socio-economic factors such as age, car ownership and gender across a synthetic population, as it is needed for the agent-based simulation.

In this regard the scenario provides a lightweight example of a complete MATSim simulation, where it is easy to test different parameters and extensions to the framework on a near-realistic baseline scenario. However, while working with the original Sioux-14 network during the course of this thesis, it became clear that the simplified structure of the underlying traffic network does not provide enough resolution for the simulation of autonomous vehicles.

The main reason is, that agents, who choose to take a car in the Sioux-14 network, probably living in the middle of the squared regions of the network,

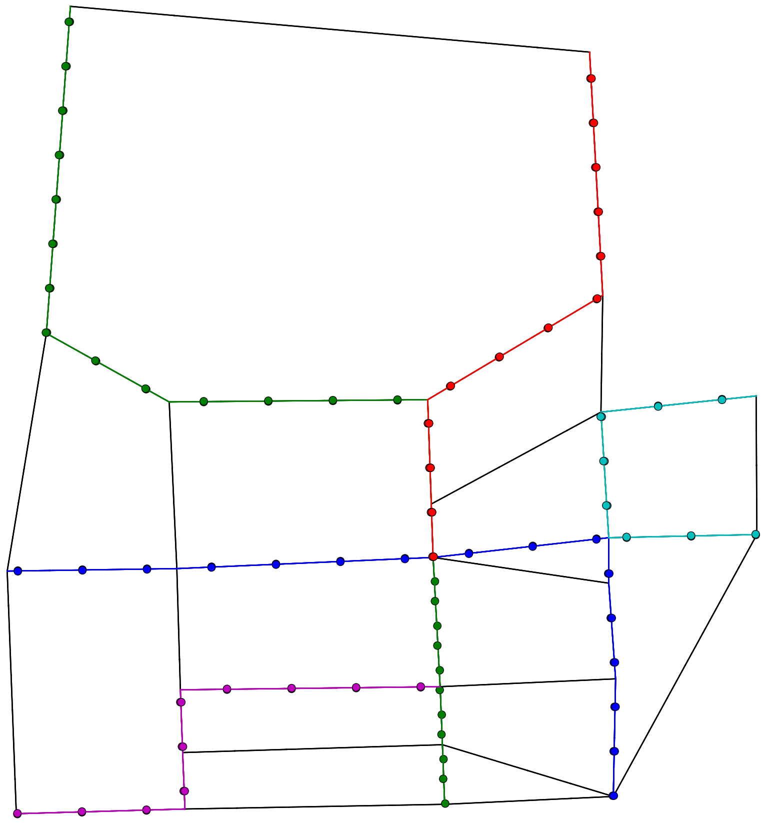

Figure 1: **TODO** todo

would be teleported to the nearest link to start their travels. This would be also true for autonomous vehicles, which is not a realistic assumption in both cases, especially when comparing it with public transport, where agents in MATSim are explicitly penalized for covering the distance between home and bus stop by foot. Furthermore effects like people being more inclined to opt for a autonomous taxi when living far from public transport can only be convincingly simulated on a finer network.

The following sections will describe how, starting from the initial Sioux-14 scenario, a new more fine-grained versatile test scenario for MATSim has been developed, which in turn has been used as the basis of the following investigations in this thesis.

The new Sioux-16 network, which has been developed for this thesis, is based on the demand model of Sioux-14, which means that all locations for homes, work places and secondary activities are kept equal, while it differs on the supply side, aiming to resemble the original scenario as closely as possible. The following sections will describe, how the Sioux Falls network from OpenStreetMap (with the state as of 18 Apr 2016) has been converted and adjusted to be compatible with MATSim and closely match the prior version of the test scenario. Furthermore it will be explained, how the public transport network has been adapted to the fine-grained Sioux-16 scenario.

1.1 Network generation and adjustment

For the creation of the new scenario, an area covering Sioux Falls has been captured from OpenStreetMap, which can be seen in fig. 2. Using the MATSim exporter in the JOSM tool [1], a simplified, MATSim-compatible network of the selected region has been created. In this process all primary, secondary and tertiary streets have been selected, while road types further down the hierarchy (for instance residential streets) have been omitted.

However, some adjustment was needed in order for the network to play nicely with the given facilities from the Sioux-14 scenario. Most importantly, the network from OSM was defined in the EPSG:3857 coordinate system, while Sioux-14 uses

[1] https://josm.openstreetmap.de/

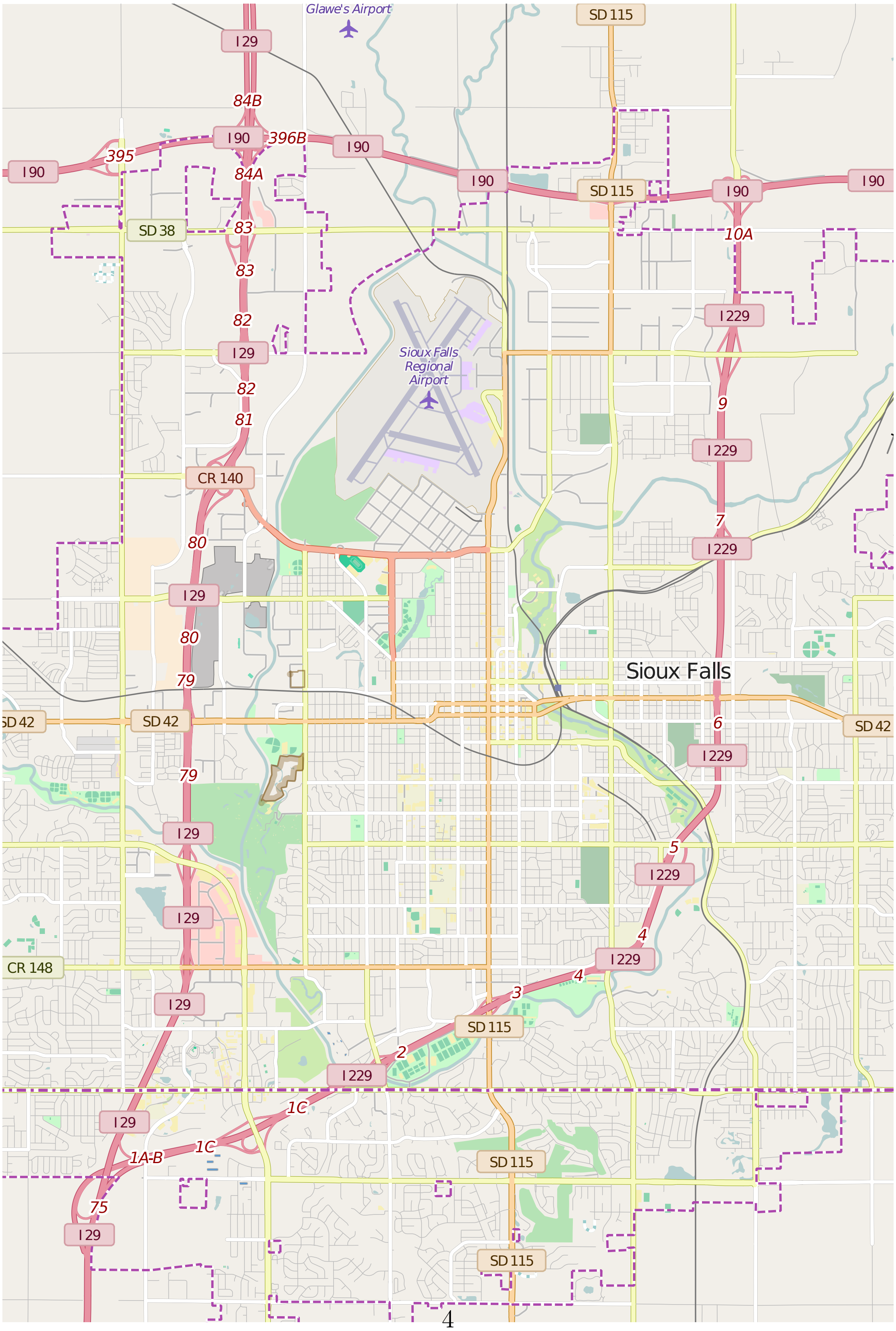

Figure 2: Map of Sioux Falls from OpenStreetMap. Longitude from $-96.8105°$ to $-96.6653°$ and latitude from $43.4729°$ to $43.6286°$.

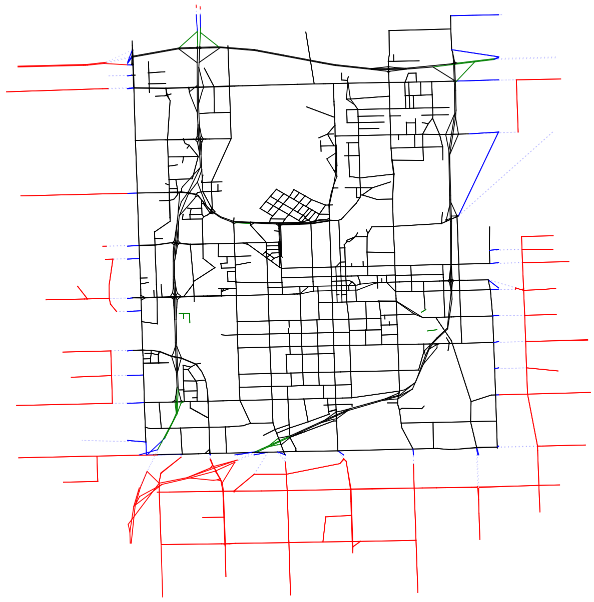

Figure 3: **TODO** todo

EPSG:26914. Therefore, in a first step, the coordinates of all the generated nodes needed to be converted to the old system.

In a second step, the positions of all facilities in Sioux-14 have been obtained and a bounding box with a margin of $500m$ around them has been computed. Subsequently, all links, which were located out of the bounding box, were removed from the network, while those who were crossing the borders have been cut to fit into the area. The initial network with all removed (red) and cut (blue) roads can be seen in fig. 3. In total 352 outside links have been removed and 83 links have been adjusted.

After that, a cleanup up the network needed to be done, partly because of artifacts due to the filtering of road types, partly because of the removal of the external sections. This removal was done in a couple of steps:

1. The lengths of all the links have been updated to the L^2 distance of their respective start and end nodes in the new coordinate system.

2. The network has been searched for sources (nodes that only have outgoing links) and sinks (nodes that only have incoming links). Those have been removed, because they make no practical sense. This proecdure lead to 53 removed links in total.

3. One seed node has been defined, which definitely belongs to to the street network and then by traversing the all paths from that node, it has been determined, which streets belong to the main network. All remaining nodes and links, which have become detached from this main network have been removed (11 nodes and 14 links).

4. Finally, the network has been searched for duplicate links with the exact same start and end node. Only the first of those links have been kept, which lead to the removal of 3 duplicates.

5. In Sioux-14, the links have been split such that there are no connections longer than $500m$. This procedure has also been applied to the network at hand, leading to 389 splitted links, which have been cut into a number of equal parts with less than $500m$ length depending on their overall length.

In terms of nodes, these procedures in total lead to an increase of nodes from 1392 to 1806 (ratio 0.77) and in an increase of links from 2957 to 3335 (ratio 0.89). The links that have been removed during the cleanup are colored in green in fig. 3.

1.2 Public Transport Adaptation

The adaptation of the public transport network to the new ("Sioux-16") scenario posed some challenges that needed to be solved:

- The links of the original network did not exist anymore, obviously the routes for the different public transport needed to be mapped to the new network.
- The stops from the original network could not be mapped easily to the new roads, partly because some streets in Sioux-14 were "invented", only approximating connections in the finer network on a very coarse level, but also because roads that consisted of two overimposed links for both directions

were now split up into two spatially distinct lanes (as can be seen in the upper left part of fig. 4).

In order to get a rough routing for the bus lines, the main nodes of the Sioux-14 network have manually been mapped by hand to nodes in the Sioux-16 network. This made it possible to obtain new public transport roads in terms of those guide points: For each of the lines it has been defined, which guide points should be traversed and in which order. Then, the Dijkstra algorithm (Dijkstra, 1959) with travel time as the objective has been used to find the shortest path from waypoint to waypoint. After fitting those partial paths together, the whole route in terms of the links of the Sioux-16 network have been obtained. As can be seen in the colored routes in fig. 4 this made it easy to obtain routes that take into account the specific map structure (for instance the highway on the upper left or the one way streets, which are traversed by the blue line in the center of the map).

The generation of bus stop facilities was a more challenging problem. Given the location from Sioux-14 one could roughly match the stops to links along the new routes, which worked in principle. However, using this approach, bus stops were cluttered all along the lines. With the intention of having a rather realistic network some conditions needed to be taken into account:

- The bus stops of one line should be on opposite sides of a street and not have a large longitudial distance. While satisfiying results could obtained, for instance in the center with the blue line, the same approaches did not work well for the highway connectors on the left for the green line, and vice versa.

- The bus stops of parallel lines should be at the same locations, i.e. in the center where the green line uses the same roads as the red one, the same locations should be chosen. This constraint usually interfered with the approaches that took into account the first constraint (especially in the center for the blue line).

- Finally, some of the Sioux-14 locations where completely off the network in Sioux-16, for instance for the red line, where one can see a bend in the diagonal connection, which was modelled as a straight line in Sioux-14.

Given all those constraints the best approach seemed to put in manual work with some automated help. The final approach made use of a small program, written to manually choose the stop locations along all roads and then subsequently choose which stop locations should belong to which line. In this step one did not take into account the cases of two lanes, as just the general positions needed to be known (e.g. for the blue line in the center an approximate position between the two lines would be chosen).

In another step, the locations that had been assigned for each line have been assigned to the respective links along the line. So for the blue one, the average points in between would have been assigned to a link underneath for one direction and another stop would be created for the link above. This resulted in a final set of stop locations.

Furthermore, some stop locations were actually located on one single link. This can happen if there is a link of roughly $500m$ and the stops are for instance located at $1m$ and $499m$ along the link. In those cases the network needed to be broken up at those positions. In the current scenario this leads to the splitting of only 4 links.

Finally, according to the setup of Sioux-14 the stop locations have been moved to a position normal to the link direction, with a distance of $5m$. Additionally a schedule with busses departing in $5min$ intervals has been created.

The final public transport network can be seen in fig. 4. It features 150 stops with an average distance of $520m$ and a median of $566m$. This is a result from not being able to put the stops as accurately in intervals of $600m$ as it is possible in Sioux-14. Moreover, the L^2 distance between two stops along the routes have been used instead of a measure along the actual path. The minimum and maximum distance between stops are $218m$ and$847n$, respectively.

All steps that have been described above have been implemented in a reusable and parametrized way. For instance, one could choose to allow a maximum link length of $5km$ and would still obtain a valid network at the end, probably just with a larger number of splitted links during the processing of the public transport.

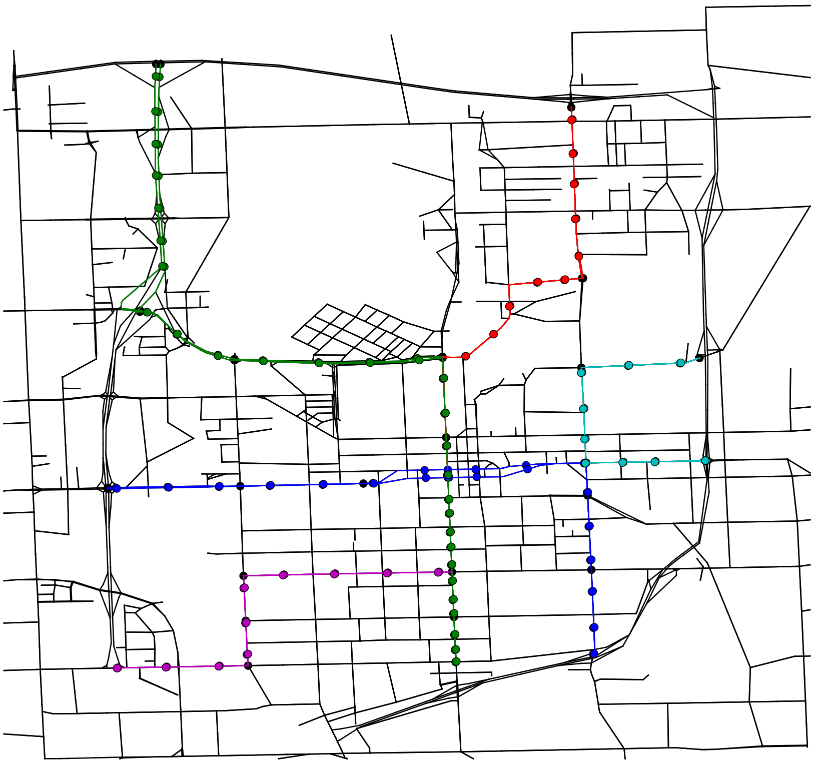

Figure 4: **TODO** todo

1.3 Scenario Calibration

The Sioux-14 network features artificially chosen link capacities, which are based on a minimum of two and a maximum of three lanes per link, where three have only be chosen for a fraction of highway links (Chakirov and Fourie, 2014). While the added minor streets in Sioux-16 should not make too much of an impact in overall capacity, the highways and main arterials of the real network usually feature greater capacity (for instance by providing *four* lanes on the western highway).

Looking at fig. 5, it can be seen that the travel time (of cars) in the new network is lower (red), compared to Sioux-16 (black). This effect can partly be explained by the increased capacity, but also by the multitude of new options to choose the most effective route for a trip through the fine-grained network. In fact, the route choice might be the major influence when comparing with the data from fig. 6. There the decrease in link speeds (relative to the freespeed) can be seen, which is quite similar, indicating a comparable amount of congestion in the network.

Depending on how important the comparability to Sioux-14 in a specific scenario is and what time of the day should be compared, it might be beneficial to adjust the flow capacity of the network[2]: In terms of travel times a scaling of 50% would resemble the afternoon peek way better than the 100% version, while the morning peek would best be recovered by a value in between (fig. 5). A similar situation arises for the link speeds in fig. 6, where a value of 50% is better suited for comparing the morning peak, while the 100% scaling creates more comparable results in the evening.

Furthermore, in terms of link speeds, it can be seen that the Sioux-16 scenario features less congestion during the off-peak hours due to the possibility of distributing trips all over the network.

A comparison of the scenarios in terms of average travel times, distances and more shares can be found in table 1. What can be seen is that averaged over the whole day, values stay roughly the same, with the biggest differences being present in car traffic. There, especially the decrease in travel distance is noticable,

[2] In MATSim, this can be easily done in the Mobsim configuration, e.g. `qsim.flowCapacityFactor` for QSim

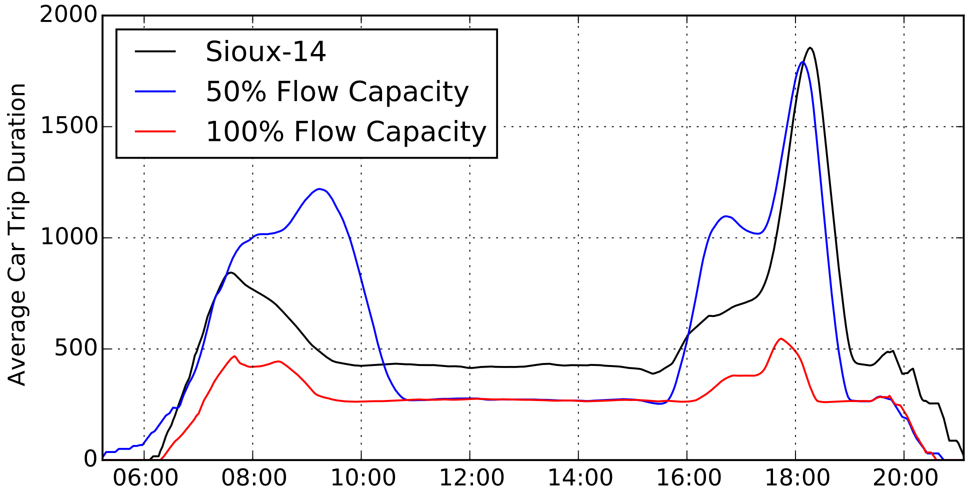

Figure 5: Comparison of the average duration of car trips by day time in Sioux-14 and Sioux-16 with 50% and 100% flow capacity.

but expected, since more direct routes can be taken. For public transport the result of Sioux-16 are similar to Sioux-14, which is an indicator that the network is strongly resembling the former version.

In terms of mode shares it is interesting to see that public transport does not see a big difference between Sioux-14 and Sioux-16 (100%), but that 3% of agents switch to using a car from walking. This effect can also be explained with the better car accessibility of destinations, where long detours would be needed in the sparse network.

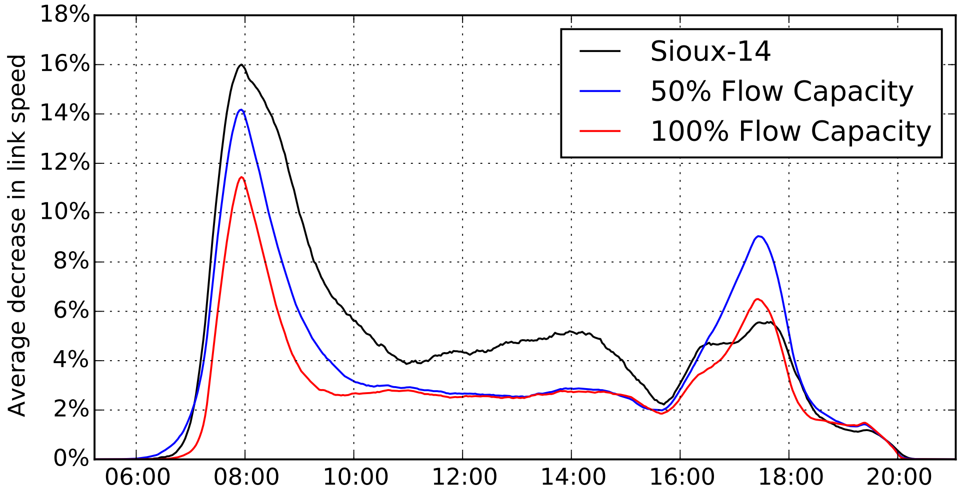

Figure 6: Comparison of the decrease of link speeds by day time in Sioux-14 and Sioux-16 with 50% and 100% flow capacity.

Table 1: Comparison of Sioux-14 and Sioux-16 in terms of travel measures

Scenario Flow Capacity	Sioux-14	Sioux-16 50%	Sioux-16 70%	Sioux-16 100%
Travel Distances [km]				
Car	2.60	1.83	1.80	1.79
Walking	1.33	1.29	1.27	1.26
Public Transport	3.70	3.82	3.86	3.89
Transit Walk	0.59	0.53	0.53	0.53
Travel Times [mm:ss]				
Car	09:00	08:39	07:01	05:12
Walking	26:35	25:48	25:19	25:08
Public Transport	31:20	29:05	28:32	28:14
Transit Walk	10:45	09:07	09:07	09:06
Mode Shares				
Car	63.52%	63.67%	65.26%	66.13%
Walking	9.44%	7.41%	6.72%	6.48%
Public Transport	27.04%	28.92%	28.01%	27.39%

2 References

Artem Chakirov and Pieter J Fourie. Enriched Sioux Falls Scenario with Dynamic And Disaggregate Demand. (March):39, 2014.

E W Dijkstra. A note on two problems in connexion with graphs. *Numerische Mathematik*, 1(1):269–271, 1959. ISSN 0945-3245. doi: 10.1007/BF01386390. URL `http://dx.doi.org/10.1007/BF01386390`.

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