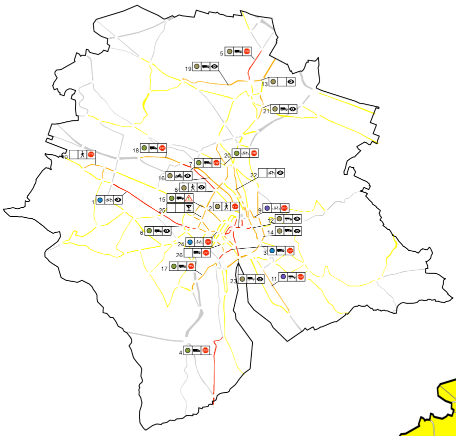

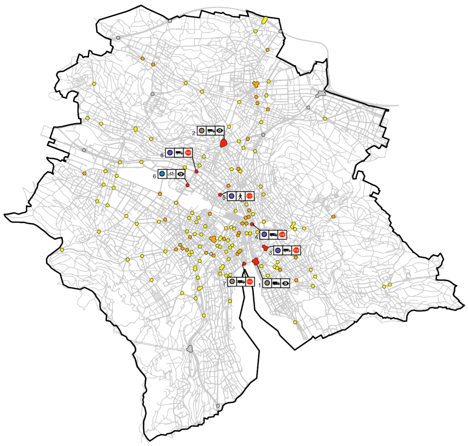

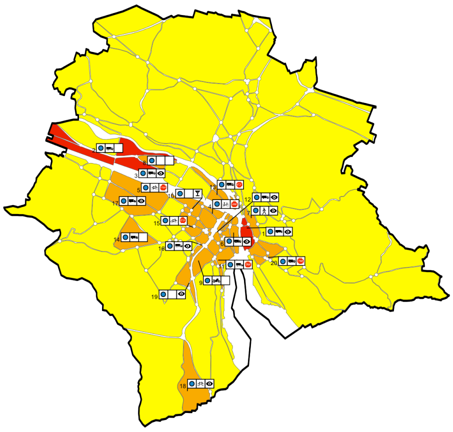

Prioritization of Road Sections in Zurich for Safety Improvement Using Network Safety Management

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In cooperation with the City of Zurich (DAV)

Master thesis
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Abbreviations

A……………………………...……………………..……………..………………..……..Accident

AADT…………………………………………………..……….…..Annual Average Daily Traffic

AC……………………………….…………………………….……...…………….Accident-cost

ACD……………………………….…………………………….…......Accident-cost-density

baACD…………………………………..…………………..……..Basic accident-cost-density

baACR………………………………..…………………………..…..Basic accident cost-rate

BSM………………………………………….……………………....Black Spot Management

FEDRO……………………………………….……………………...……Federal Road Office

FSI……………………………………….…………………………..……....Fatal or serious injury

InfraPo……………………………….………………………………....Infrastructure potential

MI………………………………….……………………………………...........……….Minor injury

N……………………………….…………………………………...……..Number of accidents

NSM…………………………………………..………………....Network Safety Management

PDO…………………………………….……………………...……..Property damage only

SN……………………………………….………………………..…...……..Swiss standard

SNR……………………………………….……………………………..……………Swiss rule

Master thesis

Prioritization of Road Sections in Zurich for Safety Improvement Using Network Safety Management

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Abstract

This thesis is a pilot-project with the goal to apply the Swiss rule SNR Network Safety Management (NSM) to the City of Zurich. The objective of this study was to explore the applicability of NSM in identifying safety hotspots in urban areas based on the infrastructure potential. The results are divided into the categories of traffic-oriented roads, intersections and residential areas. Further, a comparison of the results with and without property damage only was implemented to draw conclusions regarding the property damage only accidents. Additionally, an analysis including and excluding bicycles accidents was conducted. The comparison helped to identify the safety hotspots for the bicycle traffic.

Keywords

Network Safety Management (NSM); SNR; Section creation; Zurich.

Preferred citation style

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Masterarbeit

Prioritization of Road Sections in Zurich for Safety Improvement Using Network Safety Management

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Zusammenfassung

In der vorliegenden Arbeit wird die Schweizer Regel SNR Network Safety Management (NSM) in einem Pilotprojekt auf die Stadt Zürich angewendet. Dabei wird eine Netzeinstufung bezüglich ihres Infrastrukturpotentials innerorts durchgeführt um die sicherheitsrelevanten Abschnitte identifizieren zu können. Die Resultate sind unterteilbar in verkehrsorientierte Strassen, Knoten und Analyseflächen. Weiter werden die Resultate mit und ohne den Einbezug der Sachschäden durchgeführt um Rückschlüsse über die Wichtigkeit der Sachschäden zu ziehen. Zudem wird eine Analyse der Resultate mit und ohne Fahrradunfälle durchgeführt. Der Vergleich zeigt die neuralgischen Punkte für den Fahrradverkehr.

Schlagworte

Network Safety Management (NSM); SNR; Abschnittsbildung; Innerorts; Zürich.

Zitierungsvorschlag

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1 Introduction

In 2013 in Switzerland, 269 persons died in traffic accidents and 4’129 persons were seriously injured. A total of 17’473 accidents involving personal injury occurred. These numbers dramatically demonstrate the continuing need for safety improvement.

Road administrators aim to reduce the number of accidents with infrastructural adaptions. Yet, in a world marked by economic crisis, it is impossible to improve all the roads. Therefore, the challenge of road administrators is to assess the infrastructure safety of road sections in order to determine those sections with highest priority for improvements of the infrastructure. The Network Safety Management (NSM) outlines a methodology to evaluate the network safety in the entire network and to set priorities of road sections. It aims to maximize the safety benefit for every Rappen spent on improvement purposes.

In Switzerland, the optimization and development of the NSM is in progress. At the moment, only a non-binding Swiss rule of NSM exists. However, that rule is planned to be enacted as a Swiss norm in 2015. This thesis presents a pilot project to apply the NSM to the City of Zurich in order to provide data for the legislation process. The report is conducted and monitored by the City of Zurich.

The thesis is structured as follows: After the present introduction in chapter 1, chapter 2 presents a literature review about the NSM, SNR and the pilot-projects on behalf of the Swiss Federal Road Office (FEDRO). In chapter 3, the model approach applied in this thesis is explained. The model is applied to the City of Zurich in chapter 4 and the results are presented in chapter 5. This thesis concludes with considerations for further research in chapter 6.

2 Literature Review

This section provides a brief literature review of the Network Safety Management (NSM). The first part gives an overview of the NSM, followed by the efforts for a new Swiss standard (SN). The last part gives some insights in the recent projects on behalf of the Swiss Federal Roads Office (FEDRO).

2.1 Network Safety Management

Traditionally black spot management (BSM) is the methodology used in the European countries to identify, to analyse and to deal with black spots. In Switzerland a black spot is defined as a location where the recorded number of accidents is much higher than the average number of accidents at comparable sites (Sørensen, 2008). In the last 10 to 15 years, the BSM has been supplemented with the NSM, also called safety analysis of road networks to have an overview of the entire network instead of specific sites.

In 2003, the German “Guidelines for Safety Analysis of Road Networks (NSM)“ was released and in 2004, the French “User safety on the existing road network (SURE)“ was an approach to test 15 pilot routes with the NSM (Sétra, 2008). The result was a security approach for the existing road networks. Therefore the French and German road directors made a joint paper on NSM (BASt und Sétra, 2006). The goal in that paper is to give a methodology to analyse existing road networks in terms of traffic safety. Its ambition was to be adaptable to other European countries with an adjustment of the parameters.

At the same time Sørensen and Elvik (2008), under the auspice of the European Commission, initiated a very practicable approach to develop best practice guidelines for both BSM and NSM. This report gives a short overview over the current used methods in BSM and NSM in different European countries and tries to fill the lack of standardised definitions and methods.

Most of the reports on NSM focus on the application of NSM in the rural areas. Urban areas are only being discussed in individual cases in Germany and France (e.g. Baier, 2005).

2.2 SNR

In 2013, the FEDRO and an expert commission of the VSS (research and standardization in the field of road and transportation) customized the NSM to Swiss standards. They issued the rules SNR (2013a) and SNR (2013b). The first rule (SNR, 2013a) contains a norm of application of the NSM for rural areas only whereas the second rule includes the use in urban areas, too. A rule is a document without standard character but with the goal to get experience in the practice to lay the ground for the Swiss standard (SN).

The aim of the VSS expert commission and the FEDRO is to publish a standard in 2015. Before the consultation and publication, the implementation of pilot projects in urban and rural areas is needed.

2.3 Pilot-projects on behalf of FEDRO

The FEDRO held a kickoff meeting in the beginning of November 2013 to start with the pilot projects. Four areas were chosen to implement the pilot project of which two were rural areas (Berne, Aargovia) and two urban areas (City of Zurich and Basel).

3 Model description

The purpose of the NSM is deducing the need of rebuilding and conservation measures (SNR, 2013a). Hence, the NSM is part of the procedures for safety management of road infrastructure (ISSI) defined by the ASTRA (2011). The NSM describes a process for the analysis and evaluation of a network based on infrastructure potential, which is estimated using annual average daily traffic (AADT) and accident. An introduction to the infrastructure potential is given in chapter 3.1 before the procedure of the NSM is theoretically described in the chapter 3.2.

3.1 Infrastructure potential

The infrastructure potential is a crucial term for the NSM. It is the avoidable accident-cost-density. In other words, the amount of money, which the road owner can avoid because of planning, configuration and operation to reach a certain decrease in the frequency and severity of accidents.

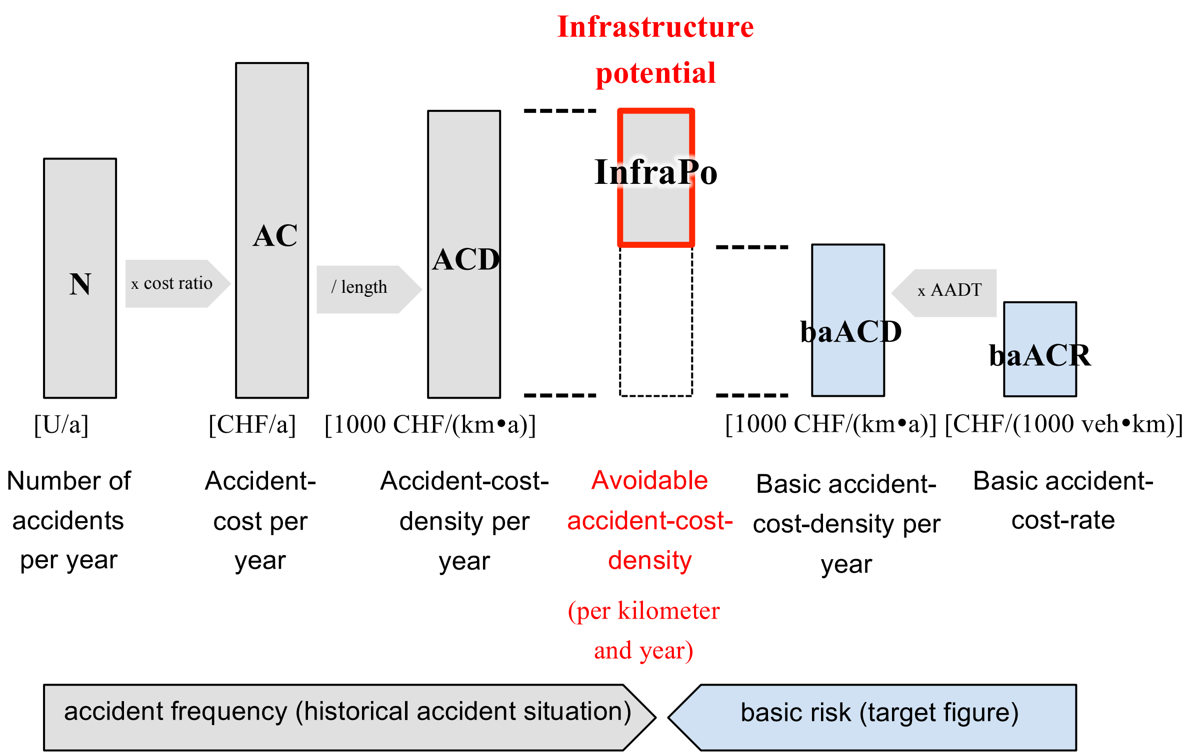
As an introduction, Figure 1 displays the calculation methodology from the SNR (2013b) in a simplified way. The methodology and procedures used in this thesis completely on the SNR (2013a,b).

The first step to calculate the infrastructure potential is to analyse the accident frequency in the historical accident situation. Starting point is the number of accidents (N) in a given network section during a defined time period. The accidents are divided into three categories:

- Property damage only (PDO),
- Minor injury (MI) and
- Fatal or serious injury (FSI).

If at least one person has an injury, it is surely not a PDO accident. Minor injury is assumed if the injured people have only minor physical problems, e.g. superficial skin injury without significant blood loss or restriction in the freedom of movement. Serious injury is defined as a severe visible impairment that prevents normal home activities for at least 24 h or requires a hospital stay of longer than one day. Fatal accident is an accident, if at least one person was killed at the scene of the accident or died within 30 days after the collision as a result of an accident (ASTRA, 2014).

Figure 1 Calculation methodology for the infrastructure potential



Source: SNR, 2013a

In a second step, the number accidents in the different categories are multiplied by the economic cost ratio, which results in the accident-cost (AC). The economic cost ratio is defined in the SNR (2013b) in table 3. If the accident-cost, in turn, is divided by the network length, the accident-cost-density (ACD) is resulting. This abstraction level allows for the comparison of two different network sections.

On the other side, the basic accident level as a theoretic basic risk results from the basic accident-cost-rate (baACR) multiplied with the AADT, which leads to the basic accident-cost-density (baACD). The basic accident-cost-density is the accident cost density that cannot be avoided by improving infrastructure. The basic accident-cost-rate is again defined in the SNR (2013a) in table 4.

The infrastructure potential the avoidable accident-cost per kilometer and year and is estimated as the difference between the accident-cost-density and the basic accident-cost-density.

3.2 Network Safety Management procedure for urban areas

This section describes the general application of the NSM to urban areas.

In the SNR (2013a,b) the procedure of the NSM is explained in general. This general procedure is now modified for urban conditions (Figure 2).

The first step is collecting the input data. The input data is defined as a network with information about roads attributes, AADT and accidents. In addition for urban areas, the traffic zones can be useful for defining residential areas (explained in chapter 4.1). If possible, the AADT should refer to the same time frame considered by the model. The accident data should be available for at least three-year period.

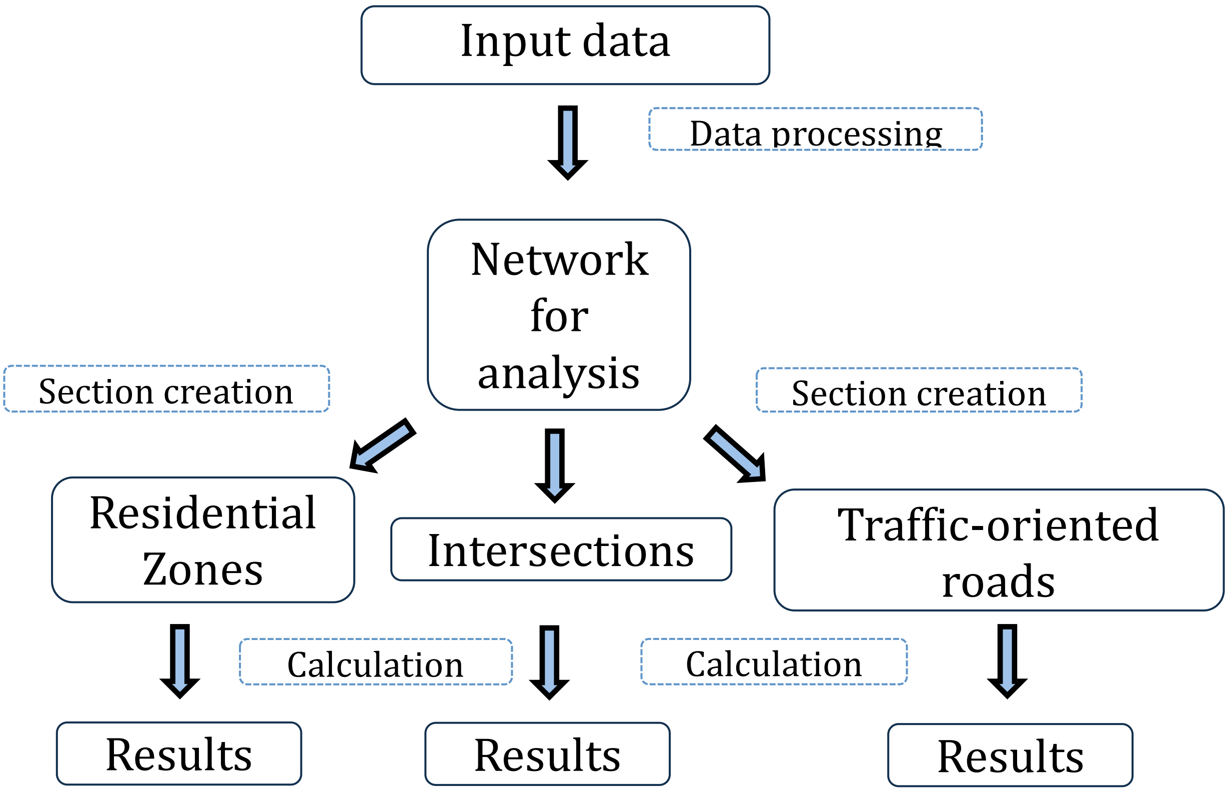
The second step consists of processing the collected data in order to reference and visualize roads, accidents, AADT and traffic zones on the axis of the network for analysis.

As a third step, the network for analysis is created by defining the intersections, the traffic-oriented roads and the roads in residential areas. The differentiation of these two types of roads is necessary, because there is a different evaluation existing. Traffic-oriented roads are defined as roads of the subordinate road network (e.g. highways, connecting roads, main roads etc.) and the analysis involves estimation of infrastructure potential.

Based on the shape, size and density of roads in residential areas and the density of buildings, the residential areas can be identified. In roads of residential areas no traffic-oriented roads should be included, because in this type of areas the transit traffic should bypass. The valuation for residetial areas is made on the basis of the accident-cost-density.

Intersections are the connections of traffic-oriented roads.

Figure 2 Sequence of work of NSM for urban areas



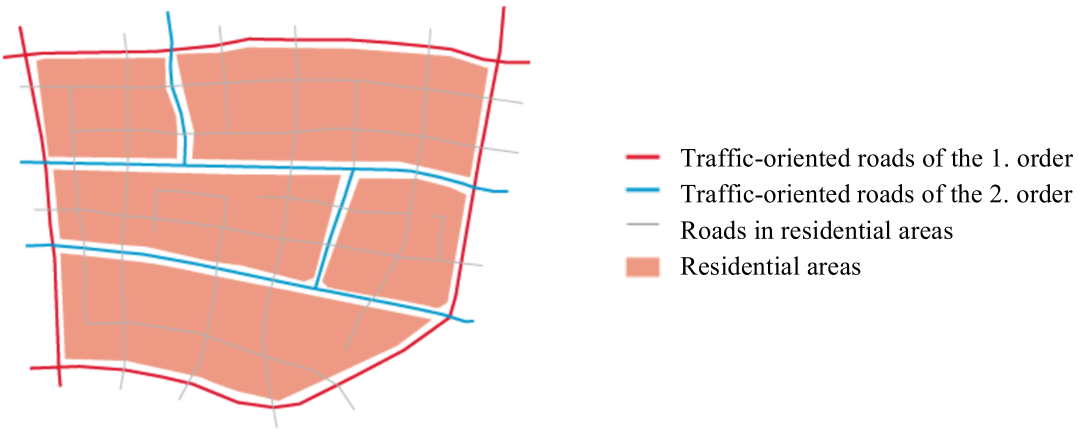
Source: Own research

In the end, the analyzed area should be divided into three different parts which together form the network for analysis.

In the forth step, for each of these three parts separately, the section creation can begin. The sections need to get comparable, that means the lengths or sizes are merged or divided in two sections. In chapter 4.4, the section creation is explained in detail.

The final step includes the calculation of the infrastructure potential followed by the prioritization of the network sections. From these results, the infrastructure potential map is drawn.

Figure 3 Differentation of traffic-oriented roads and roads in residential areas



Source: SNR 2013b

As additional steps, the SNR (2013a,b) mentions a detailed analysis and documentation of results that are included in the final report. The final report can be used, inter alia, for the network planning, maintenance management, security programs or monitoring.

4 Model application to the City of Zurich

Based on the five steps identified above, the NSM model adapted to urban areas was applied to the city of Zurich. The program used for this application of the NSM is ArcMap 10.1 from the company ESRI.

4.1 Input data

The basis of the input data is the road network, which includes the following attributes:

- Road network map (with the name of the roads),
- Speed limit and
- Nature of the road (e. g. separate tram lane).

The road network data is compiled from two shape files with data of the year 2013 netz_gesamt (Geomatik + Vermessung Stadt Zürich, 2014) and Vmax (Tiefbauamt Stadt Zürich, 2014a). All the roads with speed equal to zero are deleted. The remaining roads form a network of 1’152’740 meters total road length.

All police-registered personal accidents in the time interval from 01.01.2009 to 31.12.2013 are considered in the analysis. The data includes accidents with public passenger transportation (excluding trains). Compared with the SNR (2013b) recommendation of accident data of at least three years, the time interval of five years is on the safe side. The preparation and storage of the accident data is in the traffic accident statistics (VUSTRA) of the Dienstabteilung Verkehr (DAV) of the City of Zurich (Stadt Zürich, 2013). There were 1030 accidents with fatal or serious injuries, 4276 accidents with minor injuries and 7757 accidents with PDO. The annual average daily traffic (AADT) was obtained from the traffic model of the Canton Zurich from 2011 (Vrtic, 2012). The AADT is categorized in 7 groups:

Table 1 AADT categories

Ranking	Marking	[Veh / d]
1	—	0 – 1’000
2	—	1'001 – 5’000
3	—	5'001 – 10’000
4	—	10'001 – 25’000
5	—	25'001 – 50’000
6	—	50'001 – 100’000
7	—	100'001 – 200’000

Source: Own research

In addition, the traffic zones of the office of civil engineering in the City of Zurich are used (Tiefbauamt Stadt Zürich, 2014b).

4.2 Data processing

The data used in the study is given implemented in the appendix (A 2, A 3, A 4, A 5). For the purpose of this study, the AADT for both directions are combined to get AADT of roadway.

4.3 Network for analysis

The goal of the network for analysis is to create a network with residential zones, traffic-oriented roads and intersections that is subsequently supplemented with information of the input data. In the course of this study, it has been shown that there can be some optimisation of automation of the processes, but post processing and correcting by hand is still needed.

As shown previously, the procedure to implement the network for analysis is divided into three steps: (1) development of residential zones, (2) development of traffic-oriented roads and (3) development of intersections.

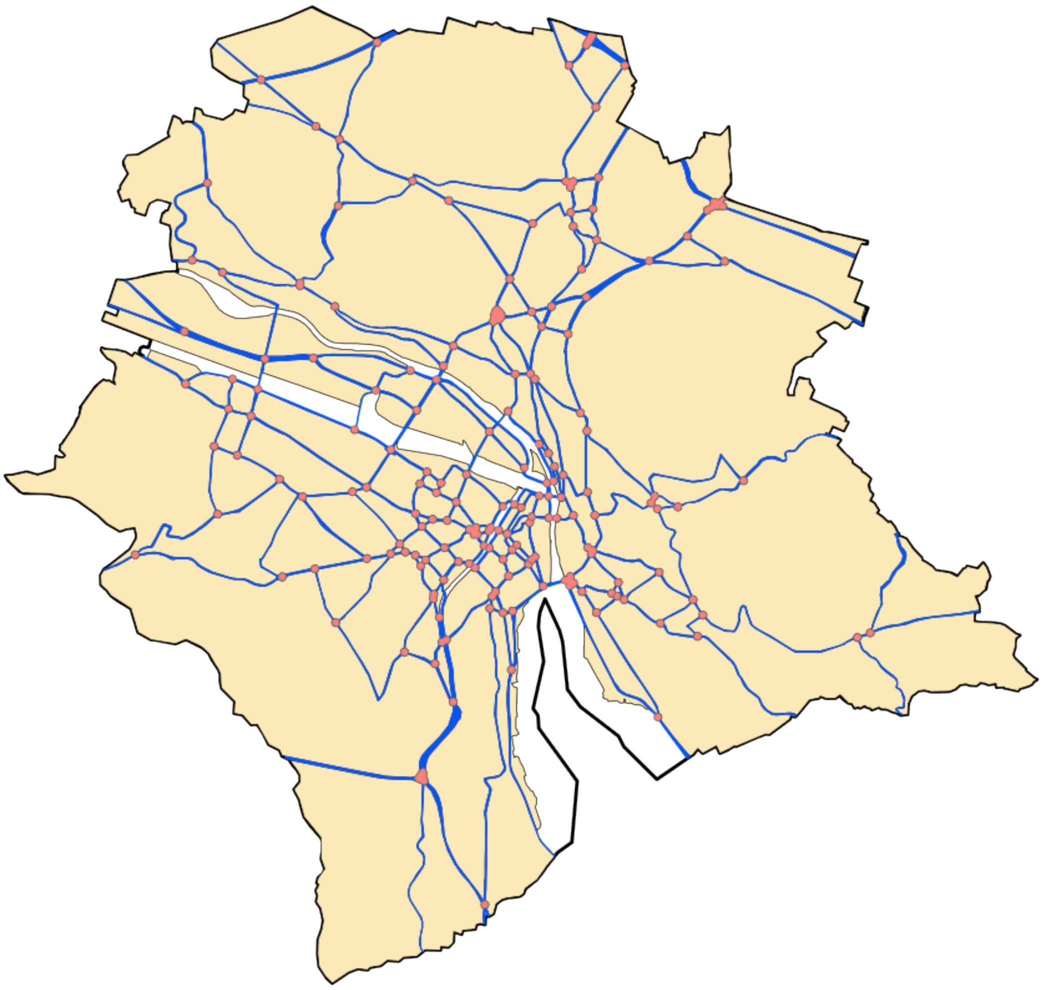
First step is to define residential zones, which are developed from the traffic zones.

Resulting from the definition of residential zones, the traffic-oriented roads can be worked out in a second step. The roads are defined as being at the border of residential zones. They are implemented in the ArcGIS as areas and not as lines to have the exact boarder. In this step, it is important to compare the traffic-oriented roads to the road ranking. The traffic-oriented roads are defined as roads with speed limit greater than or equal to *50 km/h* and an AADT higher than the category 2, *5’000 veh/d*. Furthermore, a cross-comparison with the road ranking by the swisstopo (appendix A 1) can be revealing when determining the key roads (Kanton Zürich, 2013). However, this cross-comparison cannot be more than an indicator, since swisstopo depicts a road as a traffic-oriented or connecting road, although the AADT is lower than *5'000 veh/d*. As a result, the residential zones need to be adjusted and the adjustments proceed in a loop. Hence this activity needs to repeat until a satisfactory solution is reached.

In the third step, intersections are inserted in the network as circles. The problem is that the nodes were created with a radius of *50 m* as the accidents happening within 50m of intersection are considered being influenced by the intersection. However, some intersections have an individual size and need to be examined carefully. Therefore, chapter 4.3.1 deals with the quantification of intersections.

The result of those three steps is visualized in the network for analysis as shown in Figure 4. The caramel areas stand for the residential zones. The blue lines show the traffic-oriented roads. It is clearly evident that the roads have individual sizes and match the real width of the roads and the residential zones. The red points represent the intersections. The white parts inside the area of the City of Zurich demonstrate the water areas or the train infrastructure.

Figure 4 Network for analysis



Source: own research

Finally, the sections are to be complemented with information. Table 2 displays how the information is to be inserted. The residential areas do not include information about the AADT because of a lack of accuracy. The network length in intersections is defined approximately based on radius *50 m* and the number of inlets. In chapter 4.5.1 this process is described in more detail.

Table 2 Information in the network for analysis

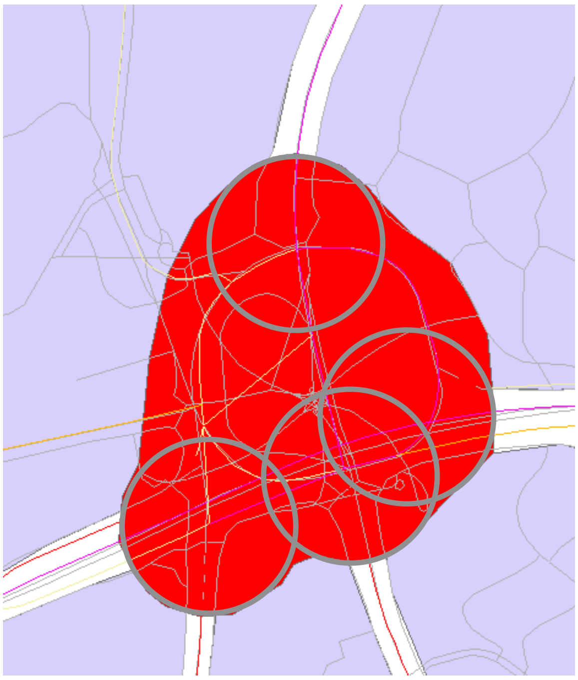
Group	Information
Residential areas	- ID - Network length - Shape area
Traffic-oriented roads	- ID - Length - Shape area - AADT
Intersection	- ID - Shape area - AADT - No. of inlet roads

Source: Own research

4.3.1 Quantification of intersections

There is a total of 166 intersections, 151 normal created intersections using circles *50 m* and 15 larger intersections with individual sizes. For large nodes, circles with *50* m cannot cover the entire intersection. Therefore, different circles with *50 m* radius were created for different areas of intersection, which resulted in overlapping nodes. Finally, these overlapping nodes were connected to form one large node (Figure 5). A unit circle radius *50 m* has an area of *7'854* m^2. The area of the individual intersections varies within the range of *10'000 – 40'000* m^2.

Figure 5 Example of a large intersection – Bucheggplatz



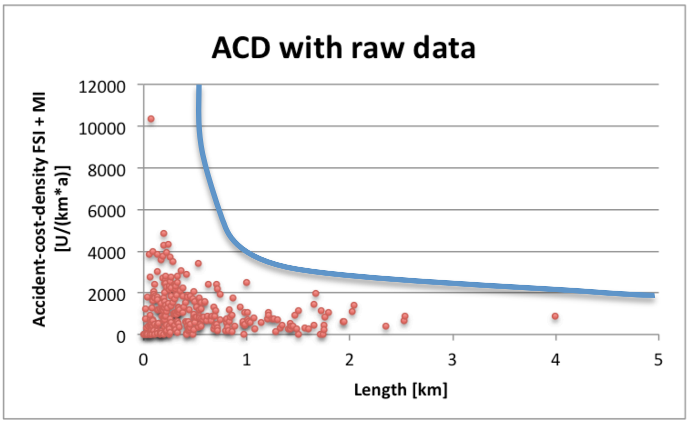
Source: own research

4.4 Section creation

In Figure 4, each single area or road segment stands for a single section. These sections are going to be connected to other sections in the neighbourhood or are going to be divided in several pieces. This artificial section creation is an instrument for the unification of sections. In compliance with Ebersbach (2008), it is performed based on the network structure. The other possibility, to create artificial sections based on the event of the accidents is not applied in the present paper.

A diagram with raw data of the traffic-oriented roads exemplifies the need of the unification of sections (e.g. Figure 6). The abscissa shows the length of the traffic-oriented roads and the ordinate the accident-cost-density. The density is calculated in accordance with Figure 1. Displayed in this diagram with the blue line, there is a dependence between the length and the accident-cost-density.

Figure 6 ACD - Diagram of traffic-oriented roads (raw data)

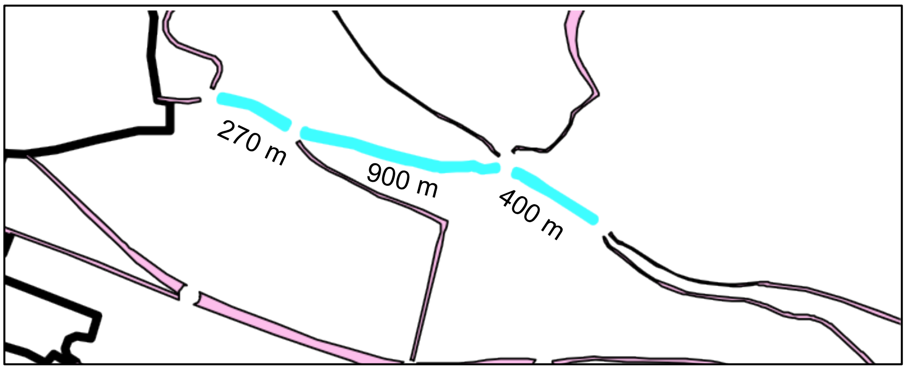


Source: own research

Smaller the road section, higher the accident-cost-density. The problem is that the calculation of a density should delete the dependence of the length. This is not given in the present case.

In the given problem, the traffic-oriented roads need to be equalized in order to decrease the dependence on small values of length. Thus, the SNR (2013b) defines minimum and maximum network lengths for traffic-oriented roads. For the urban areas, *0.5 km* is the minimum recommended length and *2 km* the maximum length (e.g. Figure 7).

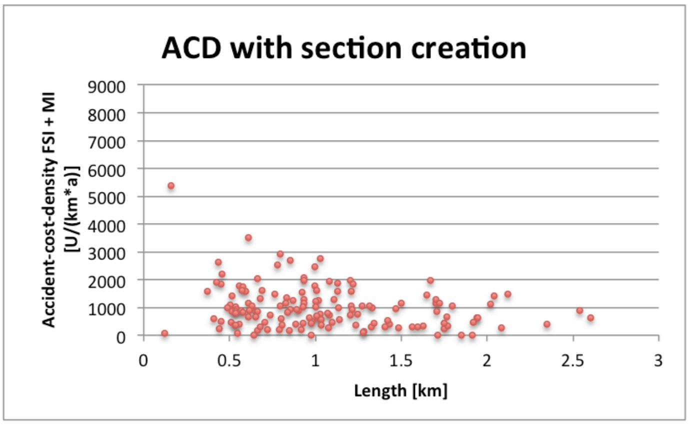
Figure 7 Example for the section creation



Source: own research

The accident-cost-densities for corrected roads are shown in Figure 8. As a consequence of the standardization, the dependence of the length has nearly disappeared. Still there are some road sections, which are smaller than *0.5 km* and larger than *2 km*, respectively. To face this deviation, imaginary section lengths of *0.5 km* and *2 km* were used for the purpose of calculation (SNR, 2013b).

Figure 8 ACD - Diagram of traffic-oriented roads (section creation)



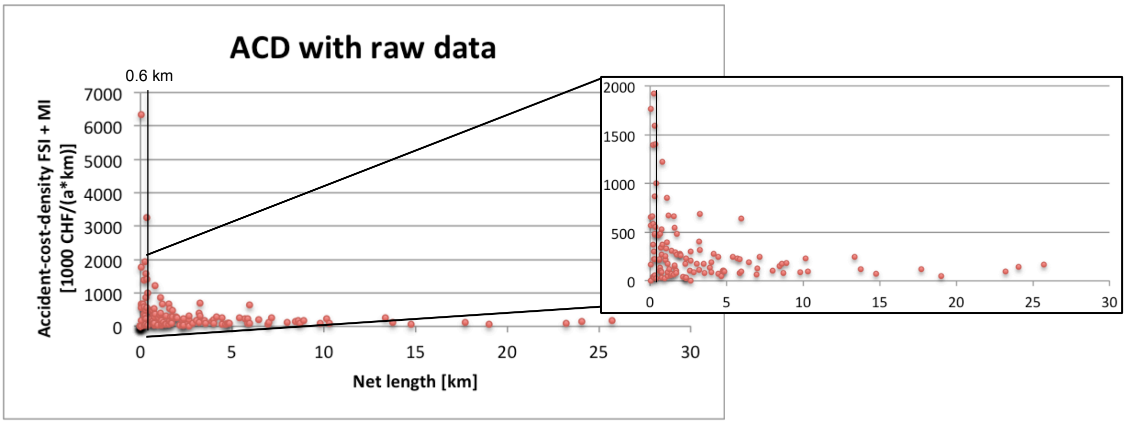
Source: own research

According to the Swiss standard (SNR, 2013b), the procedure of connecting roads shall observe the following principles:

- Smallest difference of the AADT,
- Similar construction characteristics,
- Availability of trams and
- Similar surrounding or border usage.

The same correction needs to be done with the residential areas because they are characterized by the same dependence (Figure 9). In the residential areas, the AADT does not exist, which accordingly prevents the accident-cost-density from being used as prioritization basis (problem explained in chapter 4.6).

Figure 9 ACD - Diagram of residential areas (raw data)

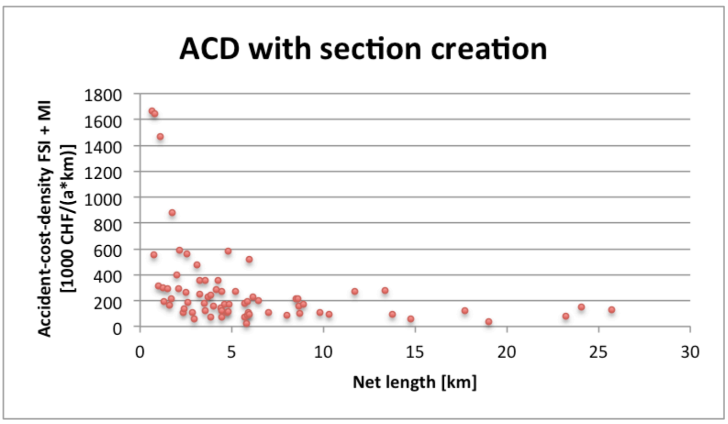


Source: own research

As a result of the section creation involving merging of nearby sections not meeting the minimum recommended length the number of sections is reduced from 272 to 175.

For the residential areas, there are no rules for the section creation in the SNR. Therefore, the minimum network length has been set at *0.6 km* and the minimum area at *0.22 km*^{2}. There is no maximum defined. An attempt to connect areas with simi-

Figure 10 ACD - Diagram of residential areas (section creation)



Source: own research

lar size, similar nature of the area or of the network length has proven very difficult in Zurich.

Finally, in Figure 10, the residential areas show less dependence on the length, although a slope of points is conspicuous. Yet, if the minimum area or network length were to be increased to reduce the slope, the accuracy would be decreased.

As a result of the section creation, the number of residential areas has been reduced from 136 to 71.

There is no need for section creation regarding the intersections. Most of the intersections have the same size and are independent from the network length.

The summarized results for residential areas and traffic-oriented roads are presented in Table 3.

Table 3 Difference of the network length through section creation

	Minimum	Average	Maximum
Residential areas			
Raw data	0 km	3.206 km	25.703 km
Section creation	.655 km	6.052 km	25.703 km
Traffic-oriented roads			
Raw data	0.003 km	.427 km	3.998 km
Section creation	0.121 km	1.050 km	2.604 km
Section creation SNR	.500 km	1.047 km	2.000 km

Source: Own research

4.5 Calculations

The calculation is based on SNR (2013b) and is explained in chapter 3.1. As shown above, to calculate the accident-cost-density, it is necessary to multiply the number of accidents by the cost ratio, demonstrated in two different ways as follows:

$$AC = A_{(FSI)} \cdot ACR_{(FSI)} + A_{(MI)} \cdot ACR_{(MI)} \quad (1)$$

$$AC = A_{(FSI)} \cdot ACR_{(FSI)} + A_{(MI))} \cdot ACR_{(MI)} + A_{(PDO))} \cdot ACR_{(PDO)} \quad (2)$$

AC Sum of the accident-costs [CHF]

$A_{(\dots)}$ Number of accidents of an accident category in a period of time [A]

$ACR_{(\dots)}$ Accident-cost-rate for an accident category [CHF · A^{-1}]

The first formula illustrates the accident-cost calculation from the SNR (2013b) whereas the second formula is an adapted version to include the PDO accidents. The different accident-cost-rates are listed in the table below (Table 4).

Table 4 Accident-cost-rates for urban roads

Accident-cost-rates [CHF · A^{-1}]			
	$ACR_{(FSI)}$	$ACR_{(MI)}$	$ACR_{(PDO)}$
Urban roads	696’500	84’000	45’000

Source: SNR 2013b

Further the accident-costs are divided by the network length and the time period under consideration to estimate the accident-cost-density [*1’000 CHF · (km · y)*$^{-1}$].

On the other hand, to calculate the basic accident-cost-density, it is recommended to use the following formula:

$$baACD = \frac{baACR \cdot 365 \cdot AADT}{10^6} \tag{3}$$

$baACD$ Basic accident-cost-density [1’000 CHF · (km · y)$^{-1}$]

$baACR$ Basic accident-cost-rate [CHF · (1’000 veh · km)$^{-1}$]

$AADT$ Annual average daily traffic [veh · d^{-1}]

The basic accident-cost-rates are listed below:

Table 5 Basic accidents-cost-rates for urban roads

Basic accident-cost-rates [CHF ·(1’000 veh · km)$^{-1}$]	
	$A_{(FSI+MI+PDO)}$
Urban roads	134
Intersections among the traffic-oriented roads	35

Source: SNR 2013b

The determination of the basic accident-cost-rate and the accident-cost-rate is explained in the appendix A-6. Infrastructure potential, which is avoidable accident-cost, can be estimated as the difference between accident-cost-density and basic accident-cost-density:

$$InfraPo = avACD = ACD - baACD \tag{4}$$

$$avAC = 1'000 \cdot InfraPo \cdot L \tag{5}$$

$InfraPo$ Infrastructure potential [1’000 CHF · (km · y)$^{-1}$]

$avACD$ Avoidable accident-cost-density [1’000 CHF · (km · y)$^{-1}$]

ACD Accident-cost-density per kilometer and year [1’000 CHF · (km · y)$^{-1}$]

$avAC$ Avoidable accident-costs [CHF · y^{-1}]

L Length of the network section [km]

This procedure was in a customised version for the three types of sections. For traffic-oriented roads, there is no need for any adaption. For intersections, the evaluation of the network length has to be simplified (chapter 4.5.1). Finally, the shortcoming of the AADT in residential areas induces an abbreviated solution (chapter 4.5.2).

4.5.1 Intersections

Based on Table 2, an approximated network length can be estimated without knowing the exact length:

$$50\,m \cdot I = L_1 \tag{6}$$

I Number of inlet roads in a given intersection [-]

L_1 Total network length in a given intersection [m]

When defining the intersections with circles of radius 50 m, this formula is a practicable approach to determine the network length for unit intersections. The same approach works also for intersections with individual sizes, only the shape of the area is larger.

The AADT in an intersection is the summed up AADT of the inlets divided by two. The reason for using only half of the total AADT is because the AADT for individual roads are bidirectional AADT. Most of the vehicles do not have their destination at the intersection itself. They pass the intersection to reach the next edge.

After obtaining the AADT and the network length, the calculation in accordance with chapter 4.5 can be performed.

4.5.2 Residential areas

In contrast to the traffic-oriented roads, the roads in residential areas are not prioritized by basic accident-cost-rates. The reason lies in the aim of planning for this road type. They are intended to minimize the foreign traffic or to concentrate the traffic in the traffic-oriented roads. Therefore, the AADT is not included in the residential areas and hence it is not possible to calculate the basic accident-cost-density, the infrastructure potential or rather the avoidable accident-costs.

4.6 Prioritization

First, the sections are to be prioritized based on the avoidable accident-costs in compliance with the SNR (2013b):

Table 6 Priority classification

Priority classification	
	Upper 20 % of the avoidable accident-costs per year
	20 % - 60 % of the avoidable accident-costs per year
	60 % - 100 % of the avoidable accident-costs per year
	No infrastructure potential (= 0)

Source: SNR 2013b

It is assumed that the avoidable accident-costs are given. In the case of the residential areas, the avoidable accident-costs are replaced by the accident-cost-density.

When creating the resulting maps, it is advantageous to visualize accident emphases in the high and possibly also medium priority sections, according to different categories, such as:

- Accident type (collision, driving accident, crossing, turn off, frontal collision, turn into)
- Participation (pedestrian, bicycle, motorbike, heavy traffic)
- Other (Distraction, disregard light signal construction, alcohol suspicion, right of way, etc.)

The database of the City of Zurich (Stadt Zürich, 2013) contains much more subdivisions. To avoid an overload of information, only the most significant and most common subdivisions are depicted. The emphasis can be developed on a local or global level. An example for development on a local level is that pedestrian accidents appear in one section more often than other possible participation accident types. The global approach, by contrast, tries to focus on the total of sections. It includes the average of the participation types in advance and highlights the significant percentage in a section afterwards.

5 Results

This section presents the results obtained from the implementation of the NSM in the City of Zurich. It is structured in the three parts of the network: traffic-oriented roads, intersections and residential areas. The results are first submitted without the PDO accidents and then with the PDO accidents in order to analyse the difference. An additional analysis for the traffic-oriented roads is conducted by comparing results including and excluding bicycle accidents.

For better understanding of the maps, the following legend (from the chapter 4.4) is enclosed to explain the visualization of the accident patterns:

Table 7 Legend of the accident emphases

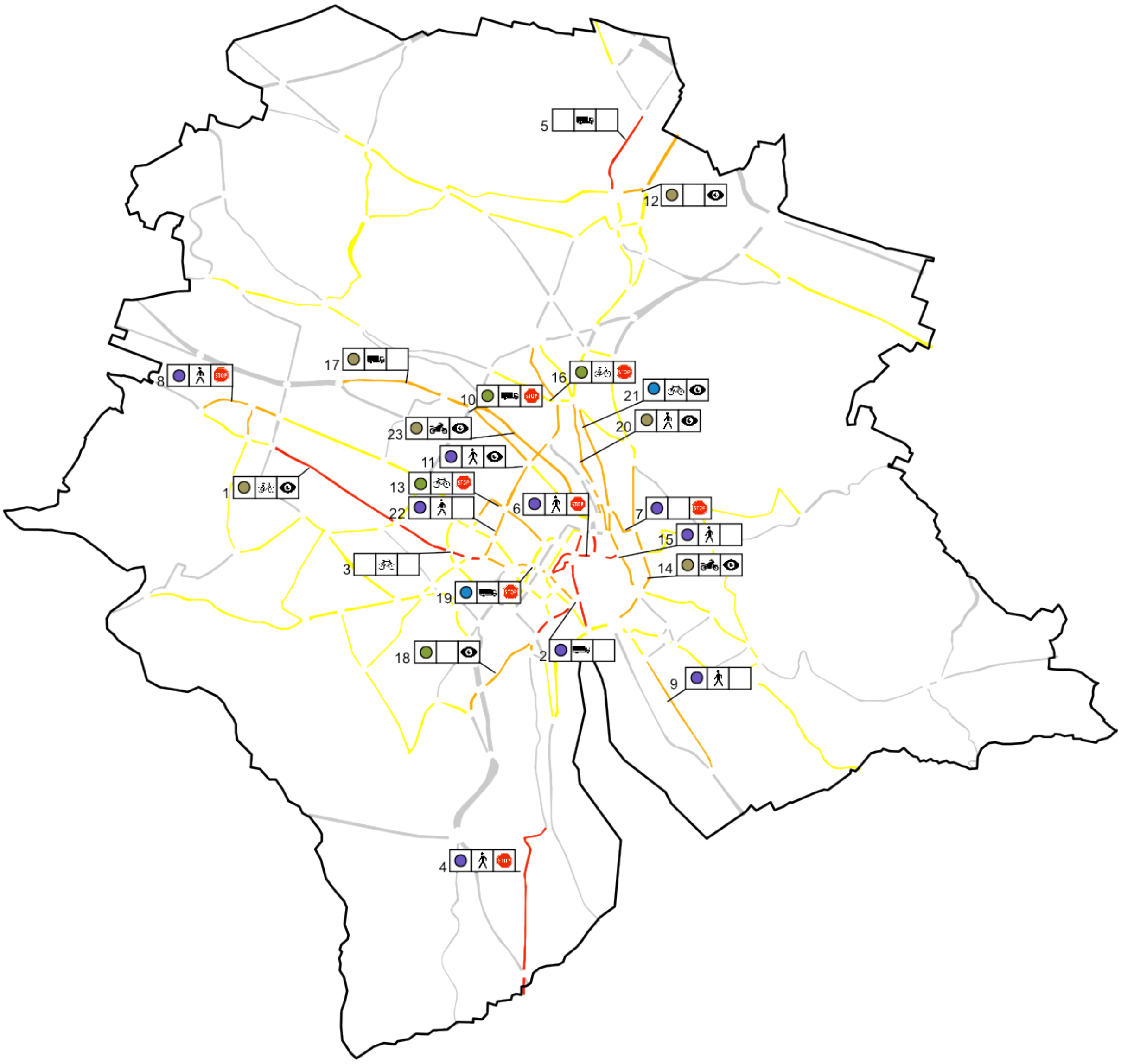
Accident type	Participation	Other
Collision	Pedestrian	Deflection
Driving accident	Bicycle	Alcohol suspected
Crossing	Motorbike	Disregard LSC
Turn off	Heavy traffic	Right of way
Frontal collision		
Turn into		

Source: own research

5.1 Traffic oriented roads

In Figure 11 the result map for traffic-oriented roads is displayed. Only the high and medium prioritized roads are shown in the map. The corresponding table of roads is enclosed in the appendix A 8. The calculation for the prioritization is performed by the local approach. The sections are numbered according to the ranking, ascending from no. 1 (highest priority).

Figure 11 Results of traffic-oriented roads without PDO accidents

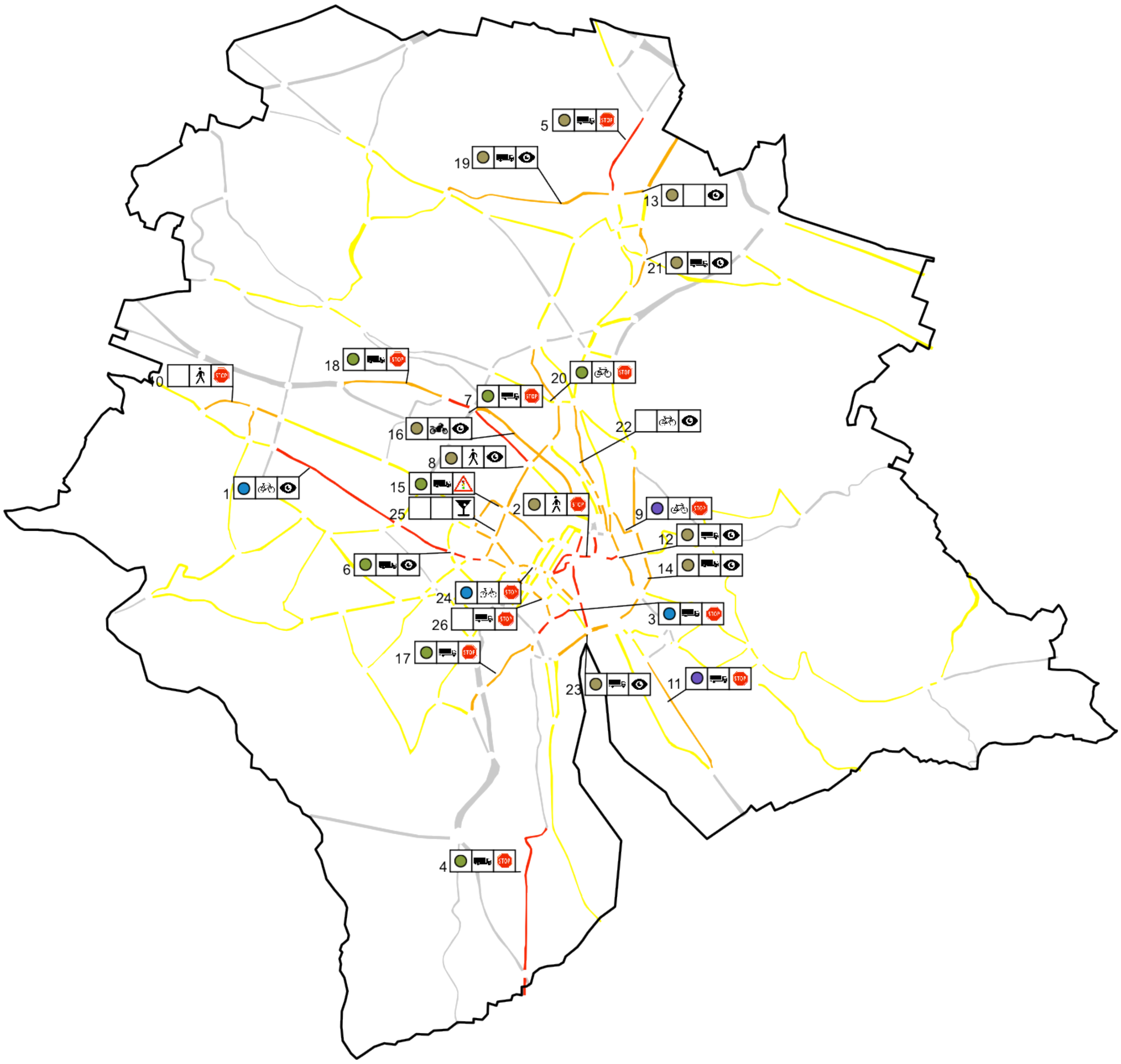


Source: own research

There are 6 sections with high, 17 with medium and 56 with low prioritization based on the results not considering the PDO accidents.

The next figure shows the results including the PDO accidents (Figure 12).

Figure 12 Results of traffic-oriented roads with PDO accidents



Source: own research

When considering the PDO accidents, there are 7 road sections with high, 19 sections with medium and 68 sections with low infrastructure potential. 50 road sections exhibit no infrastructure potential.

Additionally, a comparison of priority order calculated by the local and global approach is enclosed:

Table 8 Local and global approach of traffic-oriented roads with PDO accidents

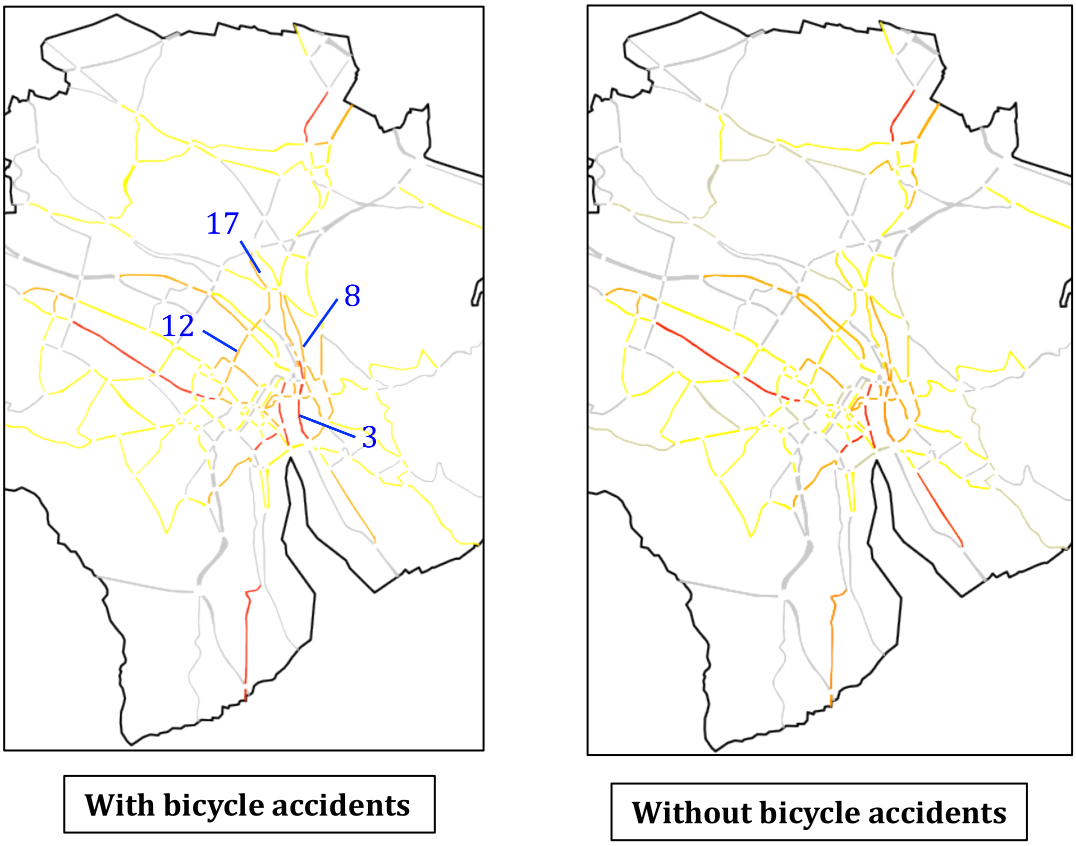
ID	Influential factors (global)			Influential factors (local)		
[-]	Accident Type	Participation	Other	Accident Type	Participation	Other
68	Driving accident	Bicycle	Distraction	Driving accident	Bicycle	Distraction
43	Crossing	Pedestrian		Collision	Pedestrian	Right of way
29	Crossing	Pedestrian	Right of way	Driving accident	Heavy traffic	Right of way
52	Turn off		Right of way	Turn off	Heavy traffic	Right of way
98	Turn off	Heavy traffic	Right of way	Collision	Heavy traffic	Right of way
10	Turn off	Bicycle	Disregard LSC	Turn off	Heavy traffic	Distraction
21	Turn off	Heavy traffic	Right of way	Turn off	Heavy traffic	Right of way
20	Crossing	Pedestrian	Alcohol suspicion	Collision	Pedestrian	Distraction
38		Pedestrian	Right of way	Crossing	Bicycle	Right of way
74	Crossing	Pedestrian	Right of way		Pedestrian	Right of way
128	Crossing	Pedestrian	Right of way	Crossing	Heavy traffic	Right of way
33	Crossing		Disregard LSC	Collision	Heavy traffic	Distraction
108		Motorbike	Distraction	Collision		Distraction
34	Collision	Heavy traffic	Distraction	Collision	Heavy traffic	Distraction
18	Turn off	Bicycle	Disregard LSC	Turn off	Heavy traffic	Disregard LSC
23	Collision	Motorbike	Distraction	Collision	Motorbike	Distraction
135	Turn off	Heavy traffic	Right of way	Turn off	Heavy traffic	Right of way
6	Turn off	Heavy traffic	Right of way	Turn off	Heavy traffic	Right of way
97	Turn into	Pedestrian	Right of way	Collision	Heavy traffic	Distraction
2	Turn off	Bicycle	Right of way	Turn off	Bicycle	Right of way
110	Turn off		Alcohol suspicion	Collision	Heavy traffic	Right of way
36	Crossing	Bicycle	Distraction		Bicycle	Distraction
26	Collision	Heavy traffic	Distraction	Collision	Heavy traffic	Distraction
16	Driving accident	Bicycle	Alcohol suspicion	Driving accident	Bicycle	Right of way
19	Crossing	Pedestrian	Alcohol suspicion			Alcohol suspicion
17	Crossing	Pedestrian	Right of way		Heavy traffic	Right of way

Source: own research

In this table, the local calculation on the right side can be compared to the global calculation on the left side. The green cells show commonalities between the two approaches, whereas the red cells indicate differences. The cells stay white if the change is not visible. With these basic conditions, it is apparent that 26 % of the cells are different in the two cases.

In Figure 11 and Figure 12 the Limmatquai is not visible and not valuated as a traffic-oriented road. The reason originates from the fact that the Limmatquai is forbidden for cars since 2004. From this, it follows that the AADT is very small, but still existing (due to the public transportation and the permission for taxis, boarding and deboarding) and it is similar to a road in a residential area. And of course, bicycles are allowed. Now, although the traffic density is very small, the accident density is very high. Therefore, in Figure 13, the given network including the Limmatquai with bicycle accidents is compared to one without bicycle accidents. This should expand the view to elaborate the hotspots of bicycle accidents in general.

Figure 13 Comparison of the results including and excluding bicycle accidents



Source: own research

In Figure 13 on the left side, the result map without the PDO but with bicycle accidents and the Limmatquai (no. 3) is depicted. On the right side, the map displays results without bicycle accidents. When comparing the two pictures, four main sections with lower priorities (no. 3, 8, 12 and 17) are recognisable. These are indicators of bicycle accidents hotspots. The differences are shown in Table 9.

Table 9 Priority classification including and excluding bicycle accidents

With bicycle accidents					Without bicycle accidents			
Ran-king	ID	Accidents 2009-13		Priority	Ran-king	Accidents 2009-13		Priority
[-]	[-]	A(FSI)	A(MI)		[-]	A(FSI)	A(MI)	
1	68	18	34	high	4	10	24	high
2	29	12	24	high	2	9	15	high
3	31	10	24	high	14	5	7	medium
4	10	11	29	high	3	8	17	high
5	52	14	49	high	7	10	38	medium
6	98	9	47	high	1	9	39	high
7	43	11	37	medium	6	8	30	medium
8	38	11	23	medium	24	5	16	low
9	74	7	34	medium	11	3	31	medium
10	128	8	27	medium	5	6	21	high
11	21	8	32	medium	10	5	22	medium
12	20	8	49	medium	22	4	39	low
13	108	10	16	medium	12	7	14	medium
14	18	6	21	medium	8	5	13	medium
15	34	8	32	medium	15	6	28	medium
16	33	8	29	medium	16	6	21	medium
17	2	7	22	medium	50	3	10	low
18	6	6	16	medium	9	5	14	medium
19	135	6	30	medium	13	5	25	medium
20	16	5	17	medium	35	2	11	low
21	36	6	22	medium	38	3	15	low
22	37	6	11	medium	17	5	6	medium
23	19	4	16	medium	31	2	8	low

Source: own research

Number 3 is the Limmatquai, 8 the Weinbergstrasse, 12 the Langstrasse and 17 the Kornhausstrasse-Rötelstrasse. These hotspots are reduced by more than 50 % when excluding the bicycle accidents. That means they are very sensitive of bicycles and prove infrastructure potential regarding bicycles.

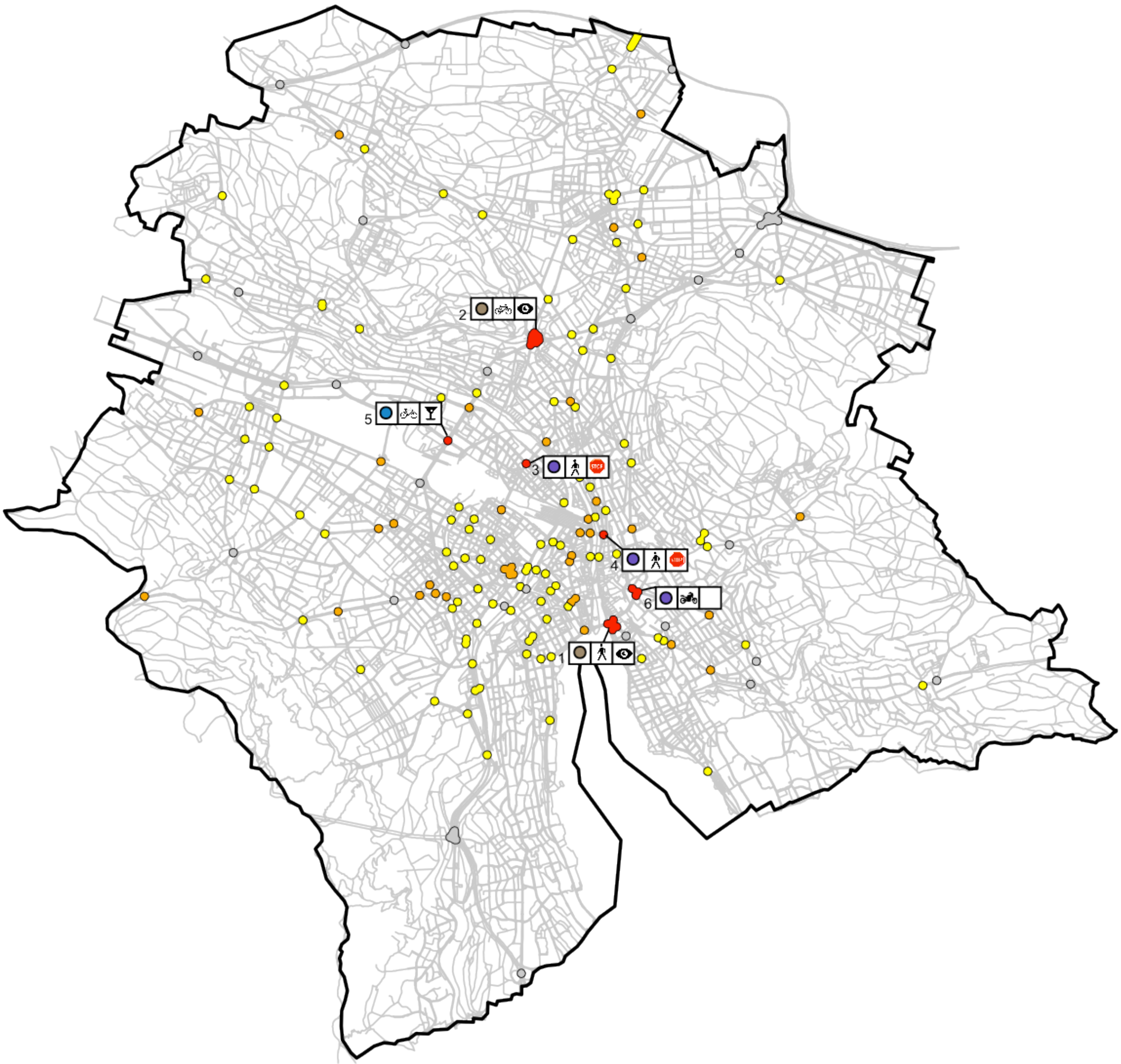
This example shows that excluding road sections like Limmatquai would not lead to identification of infrastructure improvement for those sections that actually have safety problems and has a potential to improve. More specifically, there is a need of discussion about these elements with regard to the basic accident cost rates.

5.2 Intersections

Figure 14 presents the infrastructure priorities for the intersections in the City of Zurich without the PDO accidents. For more details, see the related table in appendix A 9. The influential factors are elaborated by the local approach.

There are 6 intersections with high, 32 intersections with medium and 94 intersections with low priority. 24 intersections have no infrastructure potential.

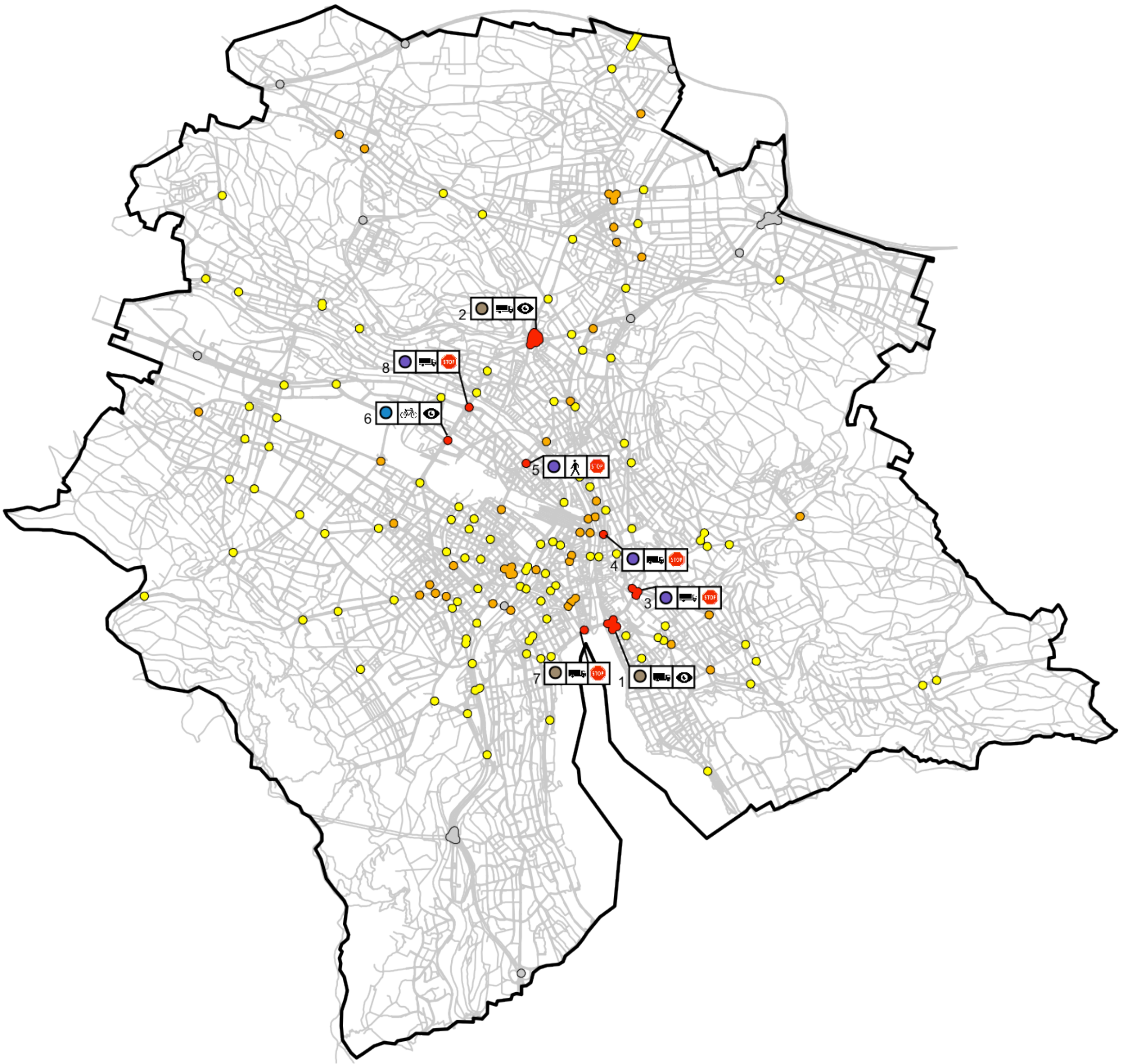
Figure 14 Results of intersections without PDO accidents



Source: own research

Figure 15 displays the results including the PDO accidents and with the local approach. The related table is enclosed in appendix A 9 with the accompanying legend. It becomes apparent, that the number of high priority intersections is raised to 8 and the number of medium priority intersections to 36. There are 103 intersections with low priority and 9 without infrastructure potential.

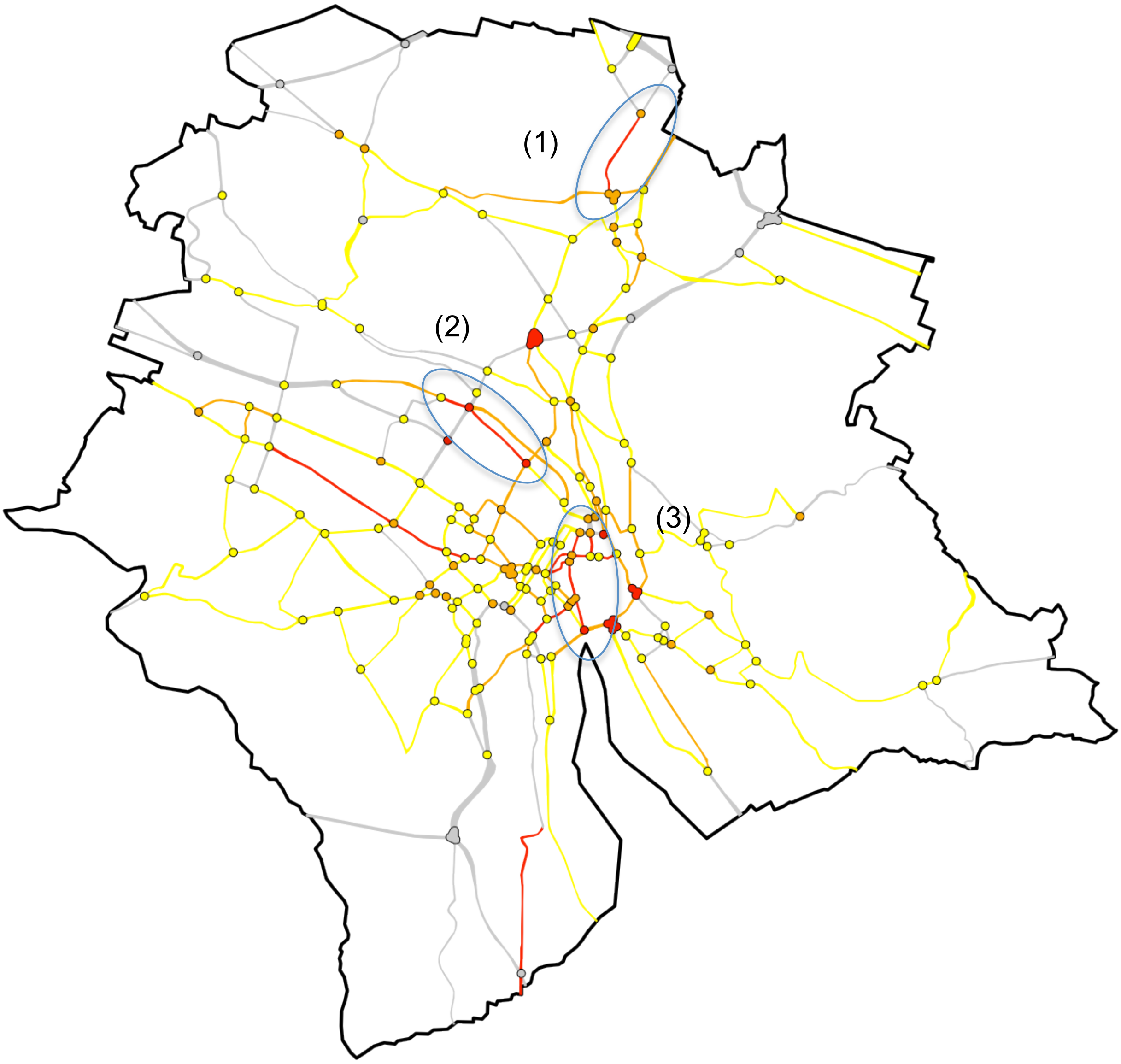
Figure 15 Results of intersections with PDO accidents



Source: own research

Finally, Figure 16 is merging results of the traffic-oriented roads and the intersections. The accidents include the PDO. The influence of the both elements is particularly apparent in three hotspots (blue circles). (1) Bahnhof Oerlikon Ost direction to Seebach, (2) Escherwyssplatz-Limmatplatz and (3) Bahnhofstrasse and its surroundings.

Figure 16 Merging results of intersections and traffic-oriented roads



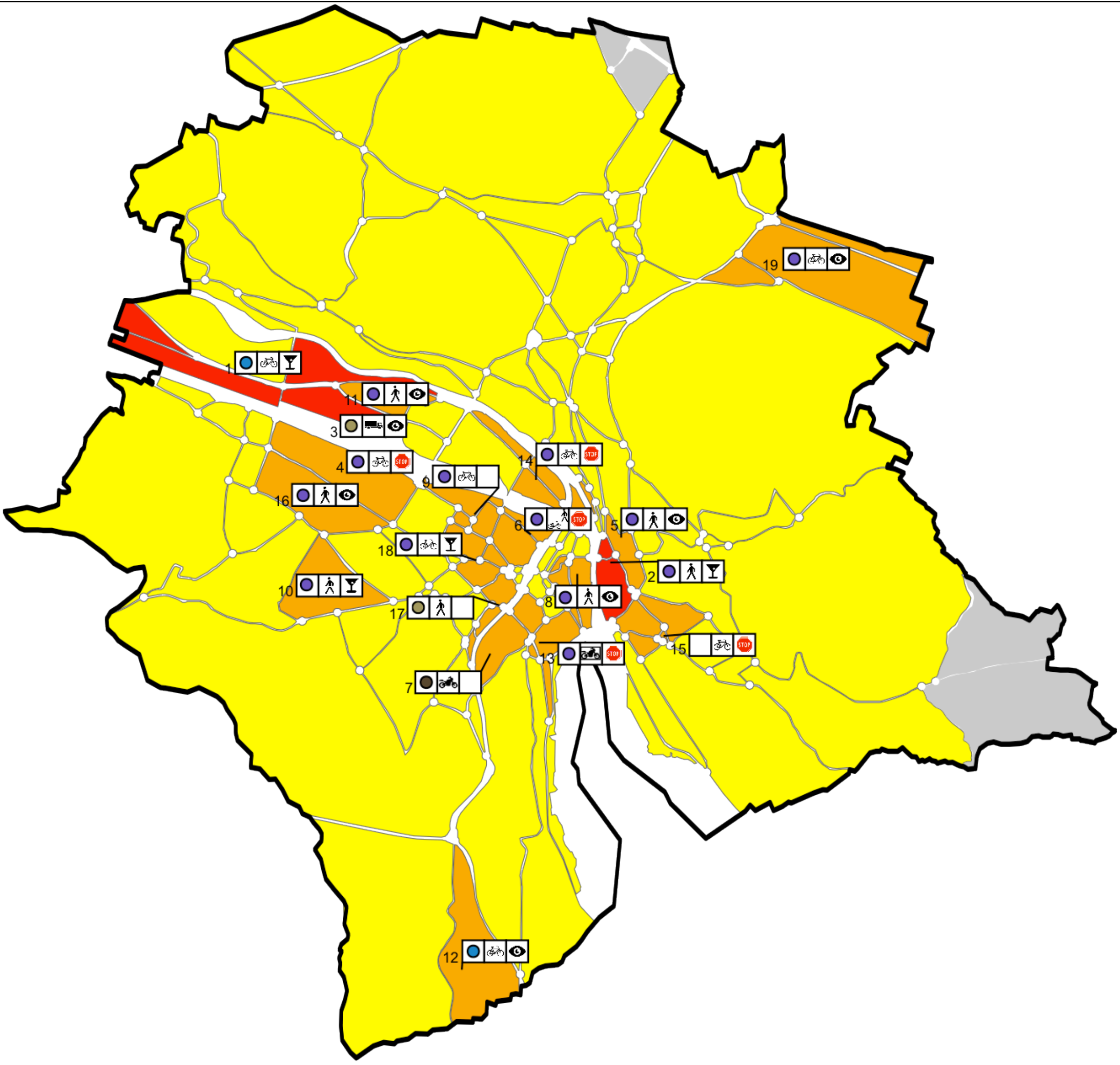
Source: own research

5.3 Residential areas

In the residential areas, the prioritization is calculated by the accident-cost-density. Therefore, almost no area without infrastructure potential exists (Figure 17). If at least one accident exists in a section, the section appears with infrastructure potential.

3 residential areas are prioritized with high, 16 with medium, 50 with low and 2 with no infrastructure potential due to the fact that there are no accidents existing.

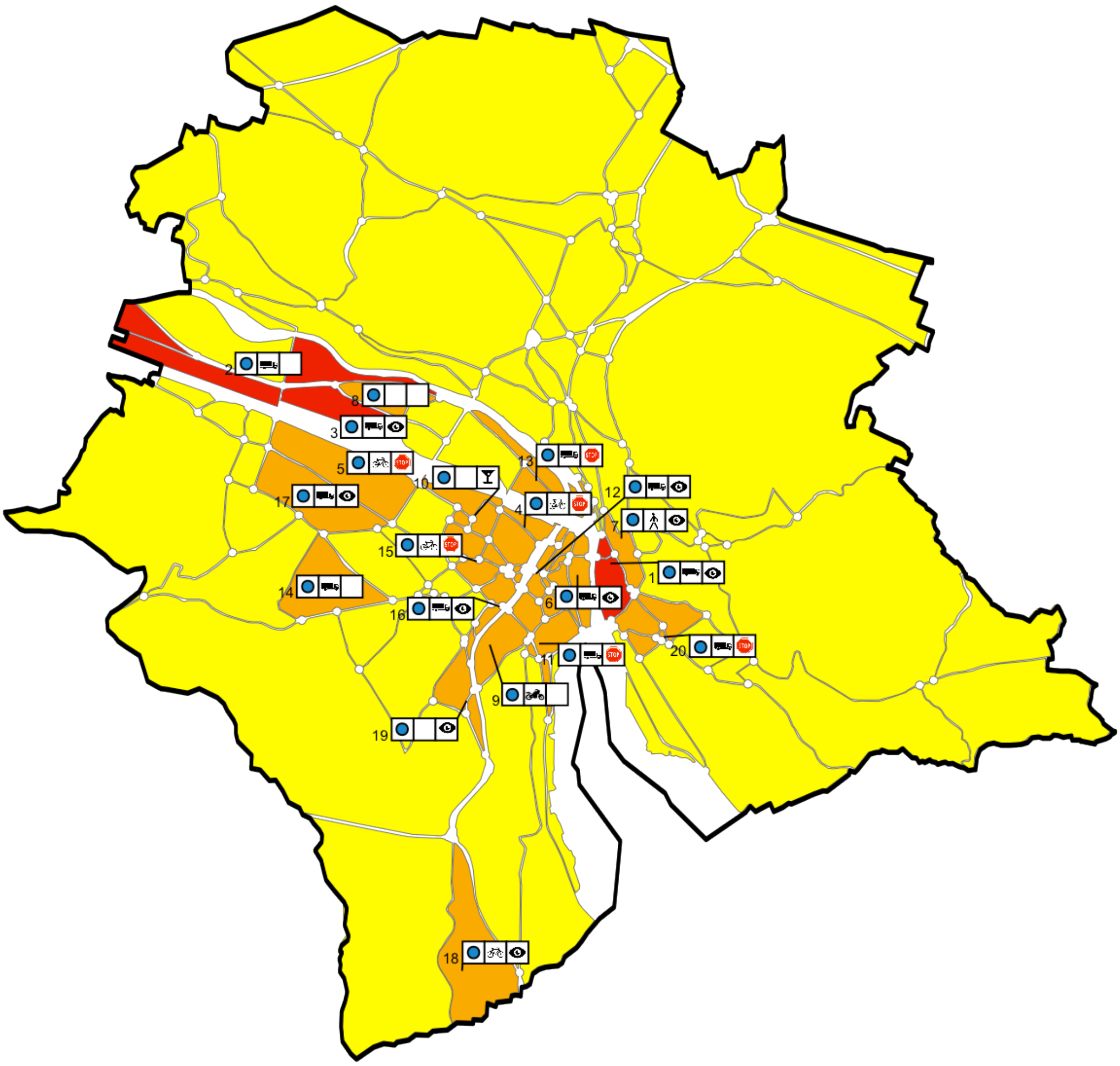
Figure 17 Results of residential areas without PDO accidents



Source: own research

Figure 18 visualizes the results of the residential areas including PDO accidents. It emerges that driving accidents are being found in every section. Throughout all sections, the accident type “driving accident” is in average the most occurring (53 %). Based on this finding, the appendix A 10 lists the tables of the results in residential areas with PDO accidents, calculated by the local and the global approach.

Figure 18 Results of residential areas with PDO accidents



Source: own research

5.4 Result overview

Table 10 and Table 11 give an overview over high-prioritized sections:

Table 10 Hotspots excluding PDO accidents

Ranking	Traffic-oriented roads	Intersections	Residential areas
1	Badenerstr.	Bellevueplatz	Industry Altstetten
2	Bahnhofstr./ Bleicherweg	Bucheggplatz	Niederdorf
3	Badenerstr.	Limmatplatz	Industry Herdern
4	Albisstr.	Central	
5	Schaffhauserstr.	Pfingstweid-/ Hardstr.	
6	Bahnhofquai, Mühle-gasse, Uraniastr., Sihlstr.	Heimplatz	

Source: own research

Table 11 Hotspots including PDO accidents

Ranking	Traffic-oriented roads	Intersections	Residential areas
1	Badernerstr.	Bellevueplatz	Niederdorf
2	Bahnhofquai, Mühlegasse, Uraniastr., Sihlstr.	Bucheggplatz	Industry Altstetten
3	Bahnhofstr./ Bleicherweg	Heimplatz	Industry Herdern
4	Albisstr.	Central	
5	Schaffhauserstr.	Limmatplatz	
6	Badenerstr.	Pfingstweid-/ Hardstr.	
7		Bürkliplatz	
8		Escherwyssplatz	

Source: own research

6 Conclusions and recommendations

This section discusses the results presented in chapter 5 and offers some suggestions for the SNR.

6.1 Conclusions

This thesis is an attempt to identify safety hotspots for the City of Zurich by using NSM. Additionally, an analysis including and excluding bicycles is conducted. Overall, the results show that a NSM analysis for urban areas like City of Zurich proves workable with some adaptions.

By using the SNR, special attention needs be paid to a number of challenges. In the course of the implementation of the network for analysis, roads, which are overlapping, or the differentiation of tunnels and residential areas cannot be designed without loss of legibility or precision. Fortunately in this thesis, the largest tunnel, the Milchbucktunnel, is operated by the Canton Zurich and therefore it is not considered in the calculation. Furthermore, the model in the SNR for urban area not exactly defines the design of intersections in highway ramps. As mostly the rural area begins in the highways, this point of intersection needs special attention.

Moreover, in the step section creation, the equal treatment of traffic-oriented roads with different number of lanes reduces the interpretability. For example, if two roads with the same AADT have different number of lanes, the traffic flow differs in every single lane. Thereby the AADT depends on the number of lanes and it is advisable to calculate the AADT per lane and not for the entire road. Additionally, the SNR should be complemented with a detailed explanation of the section creation for residential areas in order to ensure a uniform application. In chapter 4.4 the section creation for residential areas is implemented by connecting similar sections.

If we speak about infrastructure potential, it is evident to involve PDO accidents. As example, if the road is built too narrow, there are a lot of accidents caused by the miscalculation of the width. For including PDO accidents in the analysis, the authorities must record details regarding all PDO, like in the City of Zurich.

Finally, the results of the project demonstrate that the local approach for prioritization is applicable only if comparisons require several years of data if a simplified way is needed or if the global approach generates interesting results which needs further investigation.

6.2 Recommendations

The approach for the intersections with a special size has been developed specifically for this thesis. In order to equalize the results of intersections even further, it would be interesting to conduct a sensitivity analysis for the intersections. Possible variations can be estimated, such as intersections with several unit radii, individual intersections with network measuring or the implemented possibility unit intersections with special intersections.

The individual or at least further adjustment of the minimal and maximal lengths in traffic-oriented roads and residential areas is highly recommended.

In a next step, it is advised that the model developed for this thesis is extended to an automatic method where only the boundary conditions need adapting.

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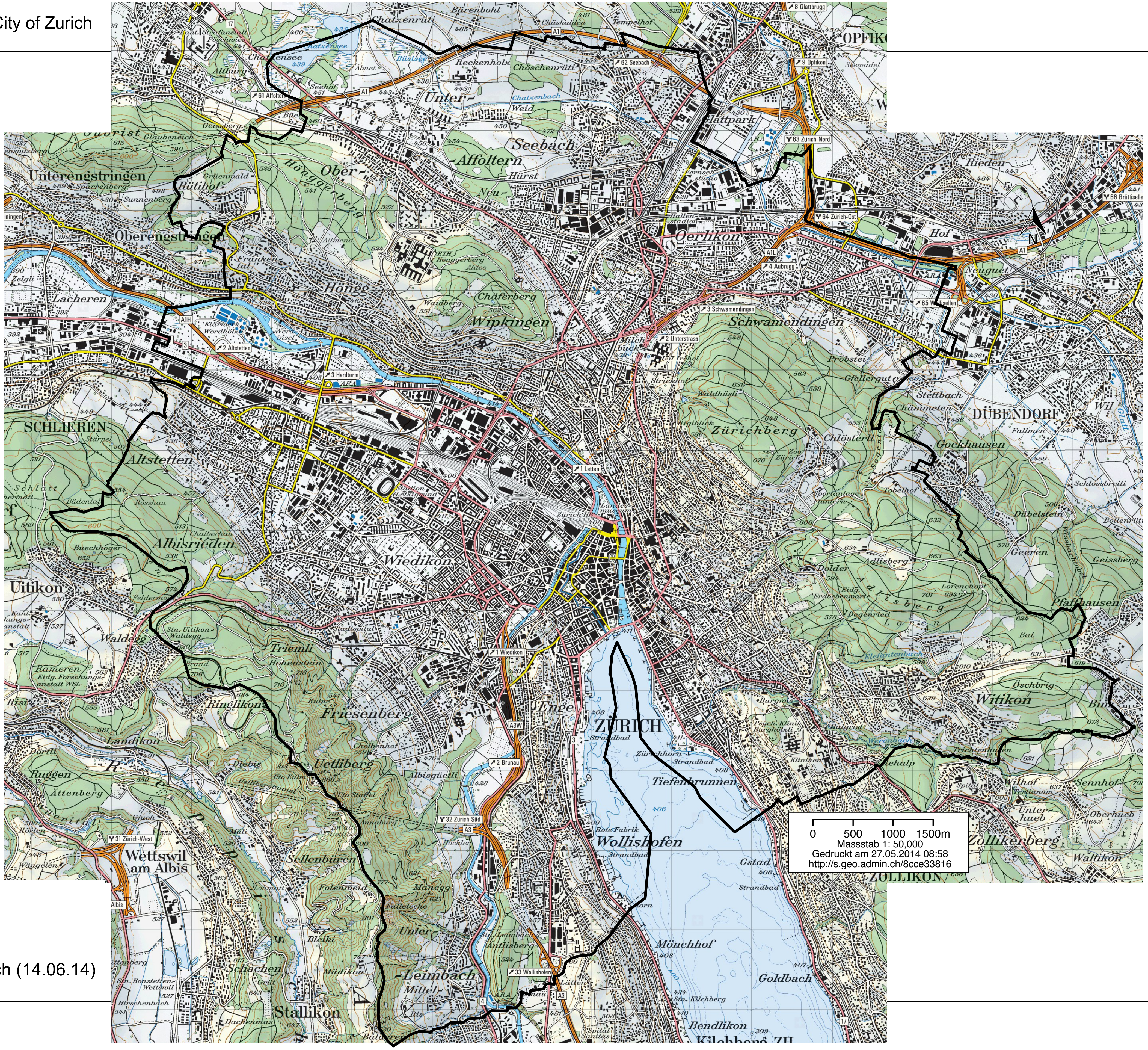
Appendix

A 1 Map of the City of Zurich

Figure 1 Map of the City of Zurich



Source: map.geo.admin.ch (14.06.14)

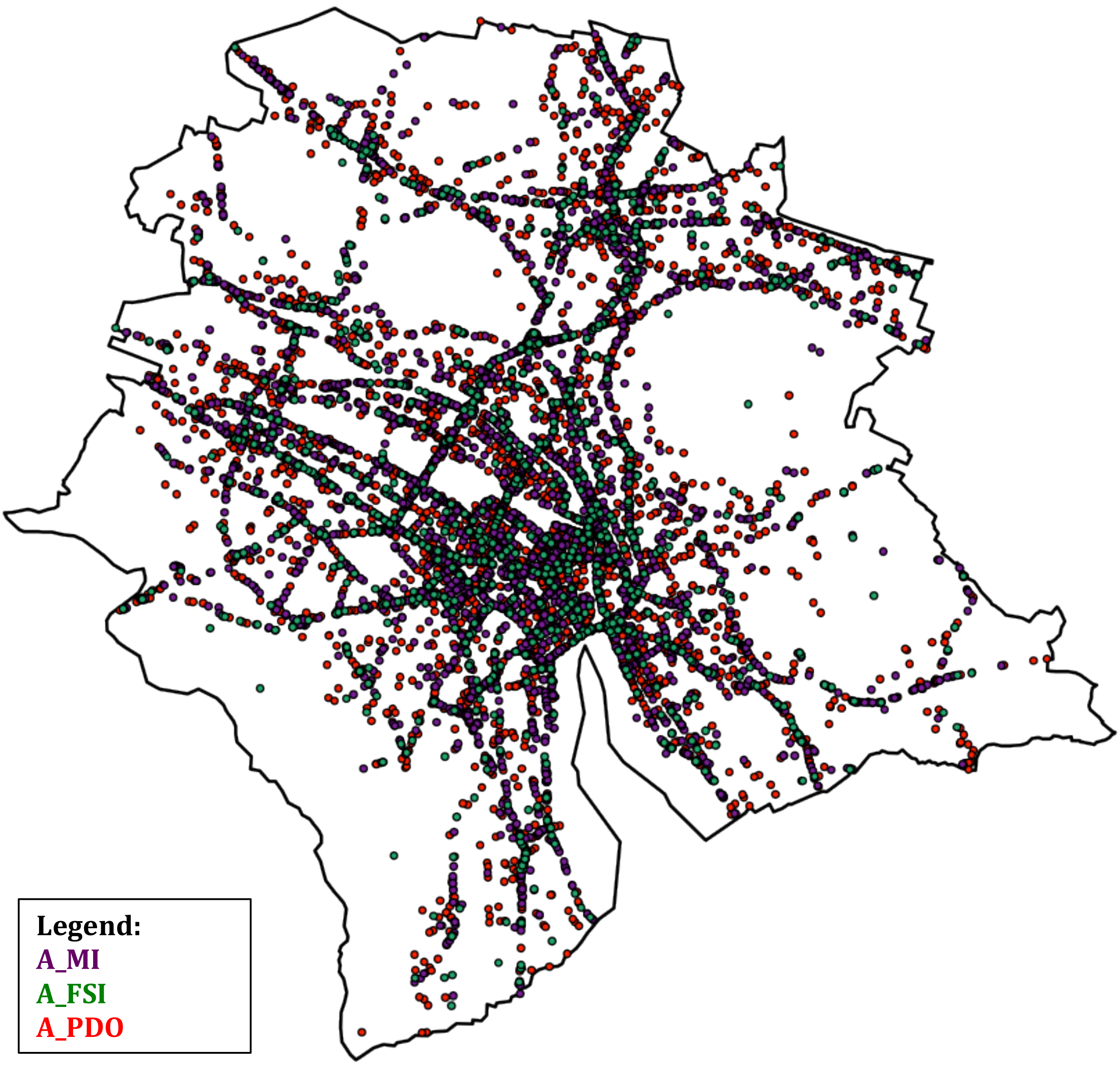
A 2 Street map

Figure 2 Map of the passable streets (v > 0 km/h) in the City of Zurich

Source: netz_gesamt (Geomatik + Vermessung Stadt Zürich, 2014)

A 3 Accidents

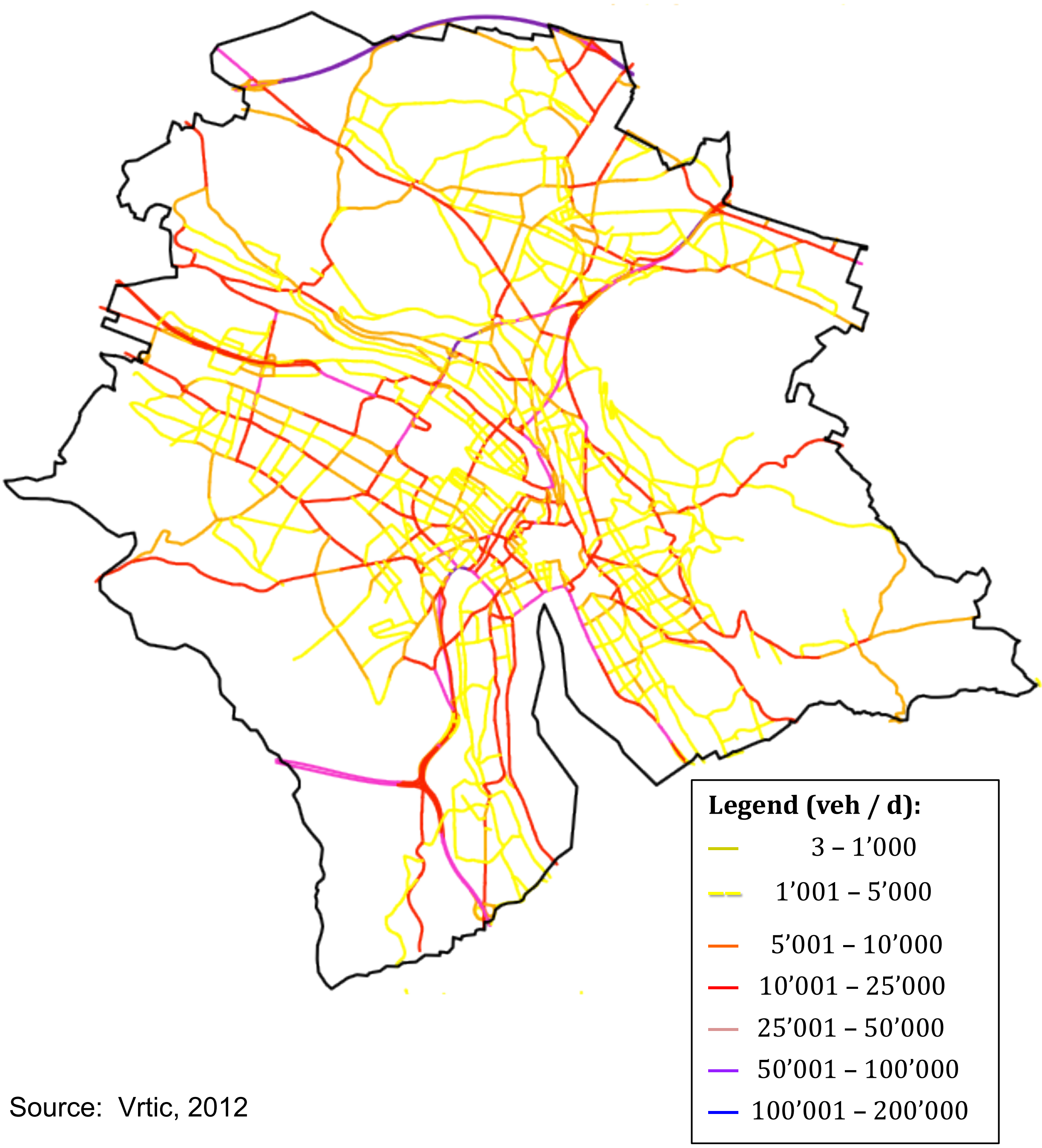
Figure 3 Map of the accidents (MI, FSI, PDO) in the City of Zurich



Source: Stadt Zürich, 2013

A 4 AADT

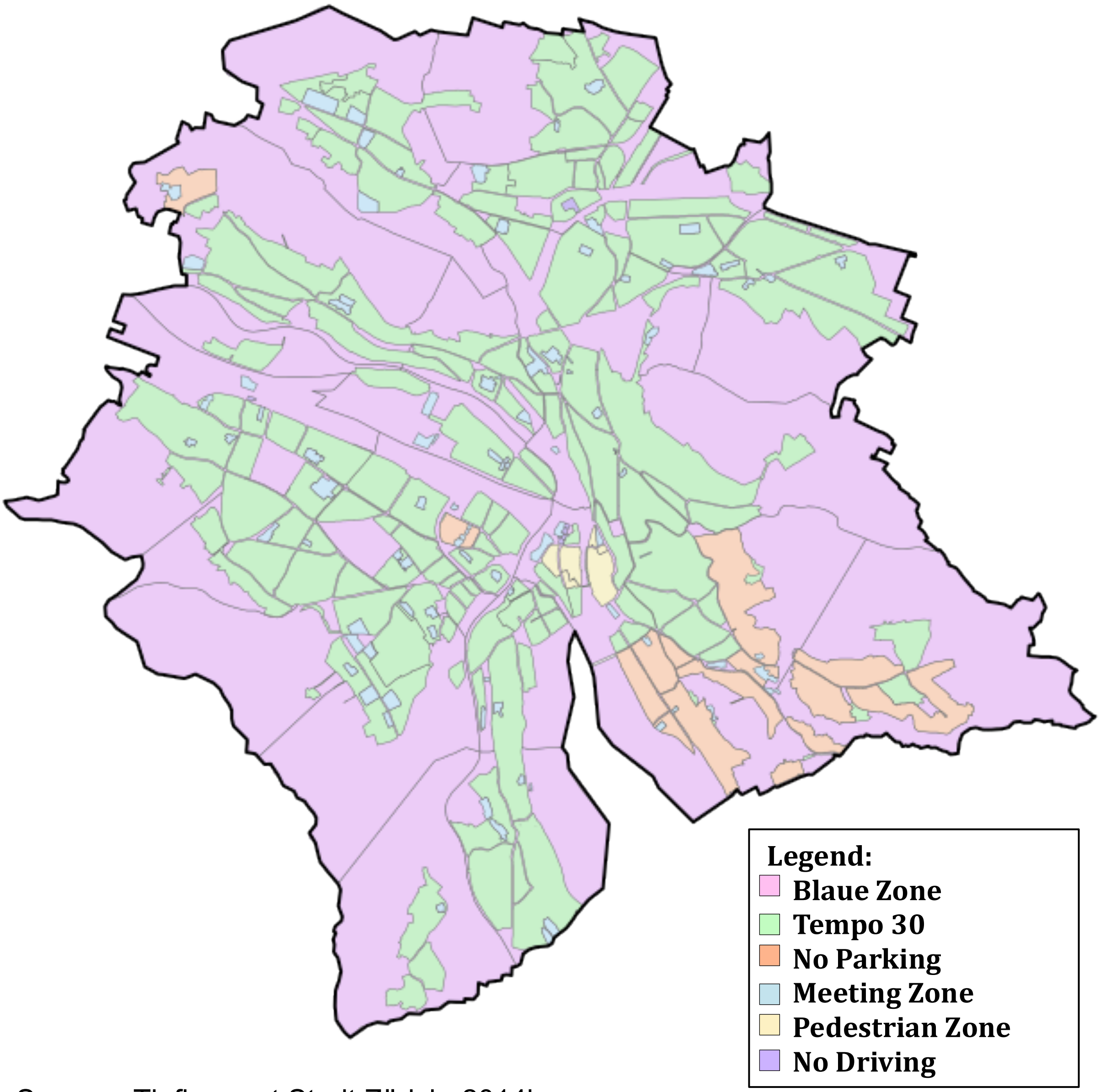
Figure 4 Map of the AADT in the City of Zurich



Source: Vrtic, 2012

A 5 Traffic zones

Figure 5 Map of the traffic zones in the City of Zurich



Source: Tiefbauamt Stadt Zürich, 2014b

A 6 Ratio determination

The ratio determination adheres to the paper from Schüller (2014).

A 6.1 Accident-cost-rate

Due to the explanation in this paper the followed cost ratio for FSI, MI and PDO in urban area can be detected:

Table 1 Cost ratio

	Cost ratio [CHF]
FSI	696’190
MI	84’126
PDO	44’824

Source: Schüller 2014

A 6.2 Basic accident-cost-rate

To modify the accidents with minor or seriously injuries in the basic accident-cost-rate, the followed formulas can derive, out of the basic of significant infrastructure influences:

$$AF_{(FSI)} = e^{-10.51} \cdot L \cdot AADT^{0.85} \cdot e^{-0.73a+0.62b+0.23c} \quad (7)$$

$$AF_{(MI)} = e^{-12.32} \cdot L \cdot AADT^{1.17} \cdot e^{-0.33a+0.48b+0.13c} \quad (8)$$

U	Accident frequency [-]
a	Presence of structural median divider (0 – no; 1 – yes)
b	Position in major cities or sub-centres of major cities (0 – no; 1 – yes)
c	Position in middle-order centres or belt of the major cities (0 – no; 1 – yes)

These formulas lead to the basic accident-cost-rate through summation and simplifications. Thereby is the parameter a determined by 1, the parameters b and c by 0 and the length by 1 km.

$$\begin{aligned} baAD_{(FSI+MI)} &= AF_{(FSI)} + AF_{(MI)} \\ &= e^{-10.51} \cdot 1\,km \cdot AADT^{0.85} \cdot e^{-0.73} \\ &+ e^{-12.32} \cdot 1\,km \cdot AADT^{1.17} \cdot e^{-0.33} \end{aligned} \quad (9)$$

$baAD$	Basic accident density [-]

In this formula the not-linear correlation of the accidents and the AADT is visible. To deduce a more simple way, the two terms of the baAD are first multiplied by the corresponding cost ratio and second averaged over the whole range of the given sample.

Finally the outcomes for urban area are represented in Table 2.

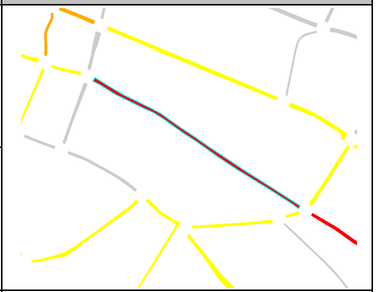
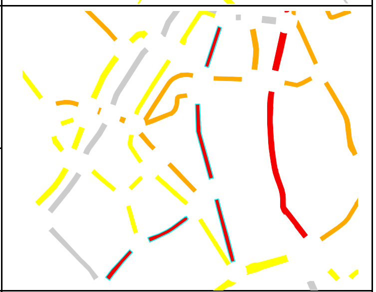
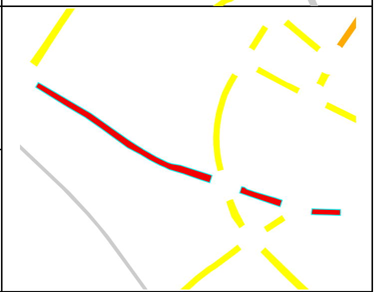
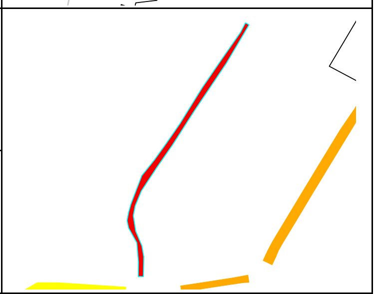
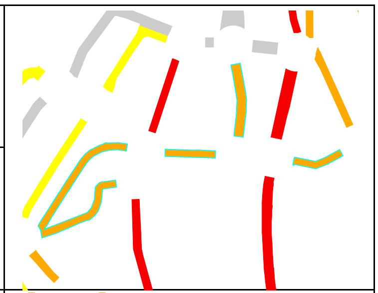
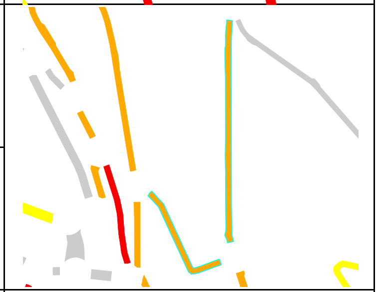
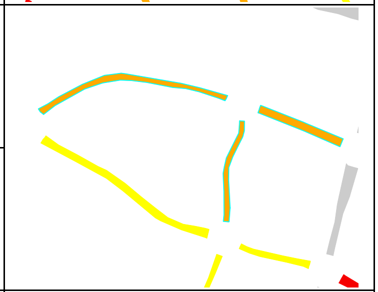
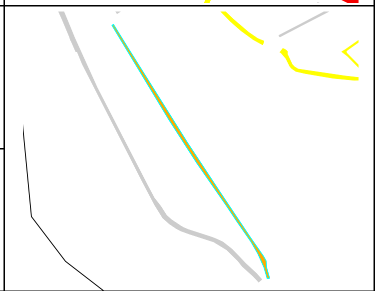
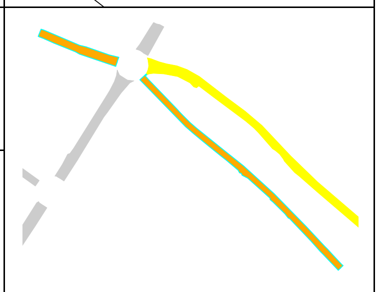
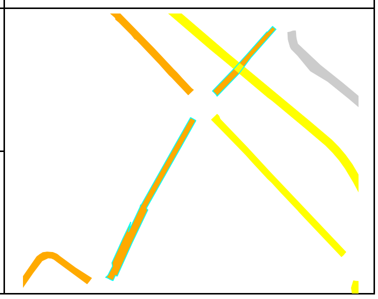
Table 2 Basic accident-cost-rate

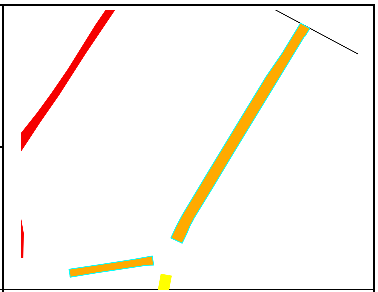
	baACR [CHF/(1’000 veh · km)]
Routes	133.8
Nodes	34.7

Source: Schüller 2014

A 7 Legends for Sections

Table 3 Traffic-oriented roads

Ranking Without PDO	Ranking With PDO	ID	Section
1	1	68	
2	3	29	
3	6	10	
4	4	52	
5	5	98	
6	2	43	
7	9	38	
8	10	74	
9	11	128	
10	7	21	
11	8	20	

12	13	
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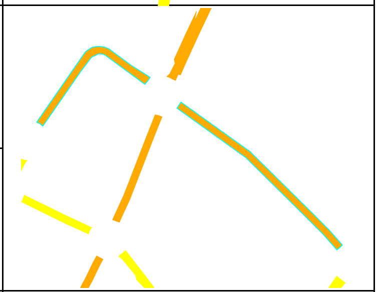
13	15	
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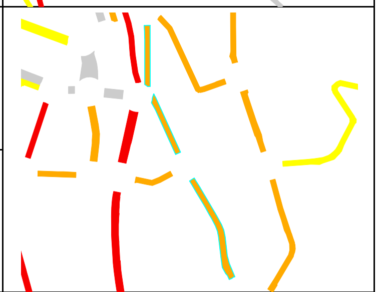
15	12	
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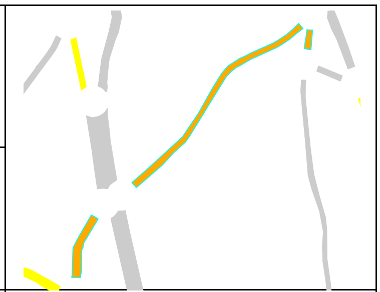
18	17	
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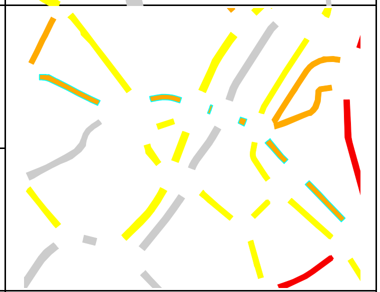
19	24	
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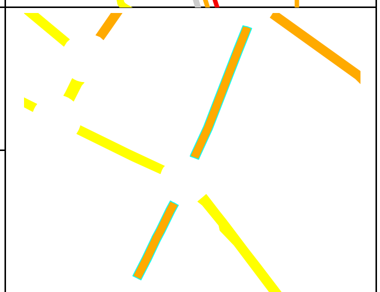
22	25	
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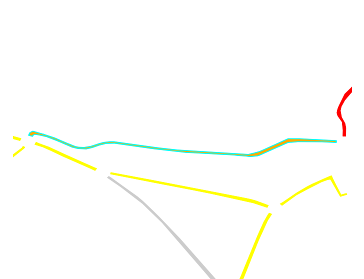
-	19	
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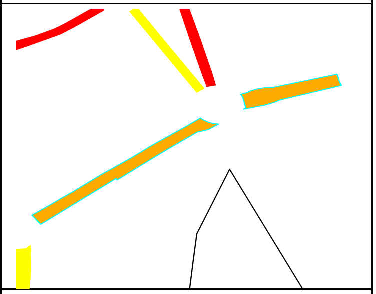
-	23	
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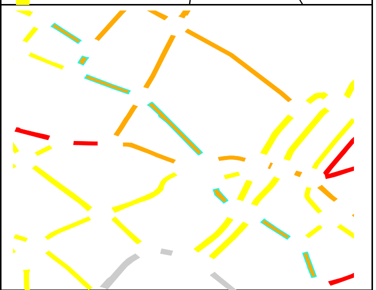
-	26	
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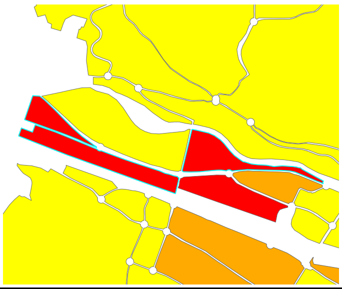
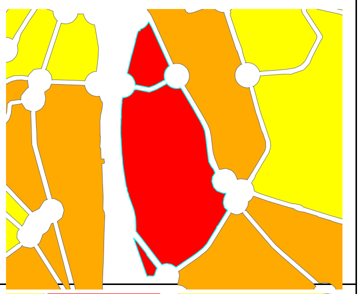
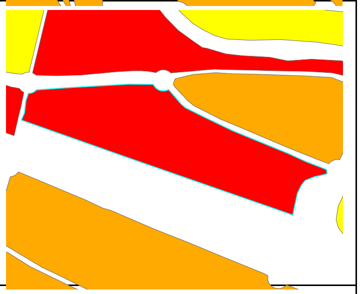
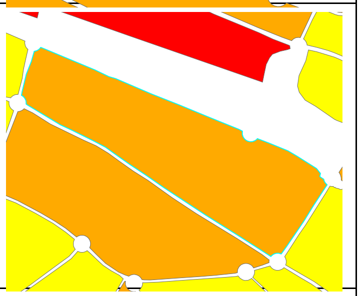
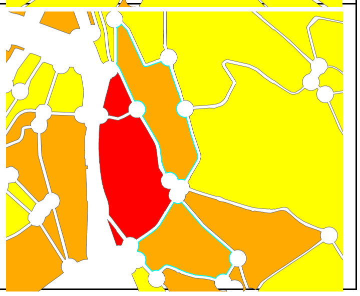
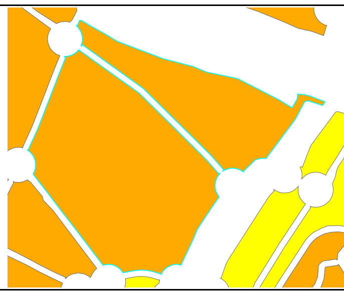
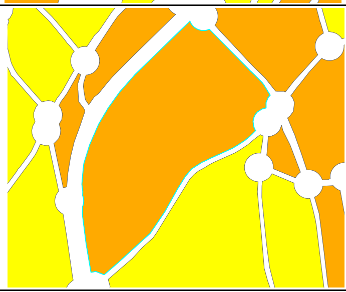
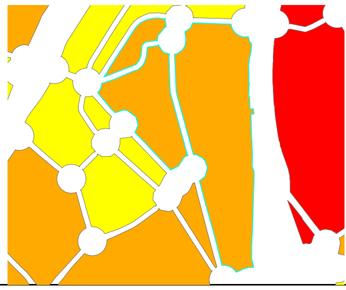
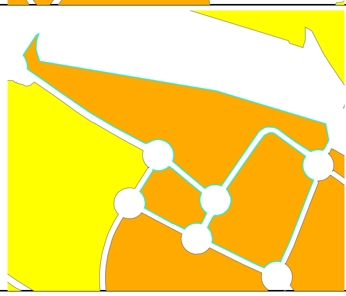
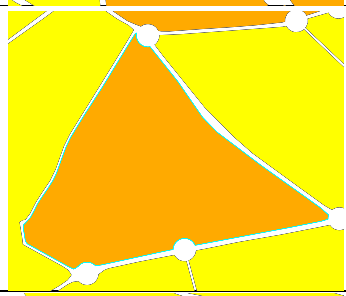
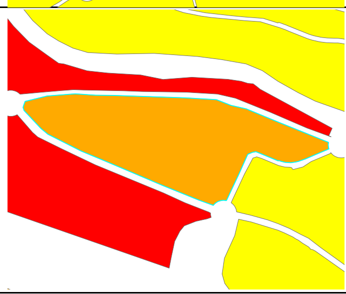
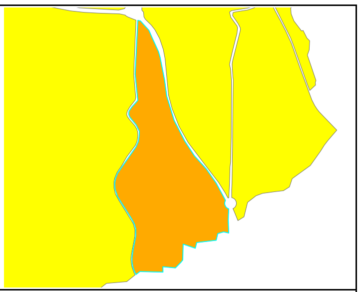
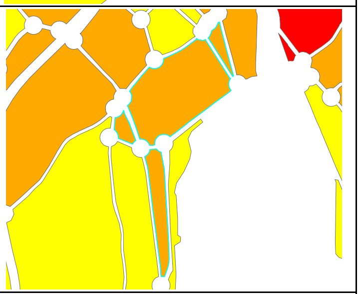
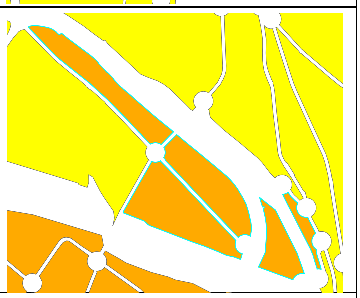
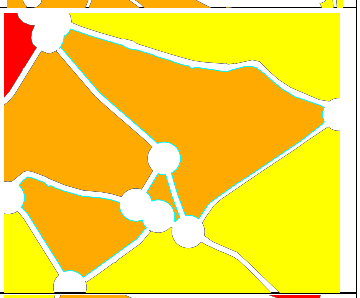
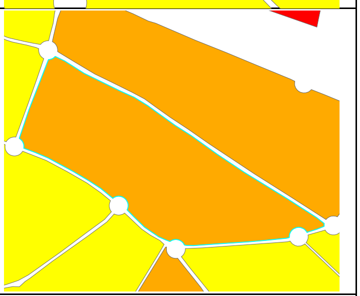
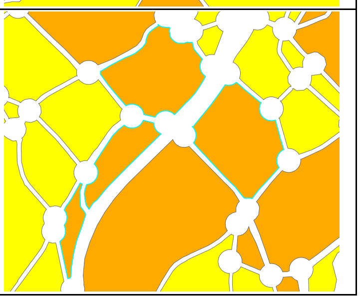
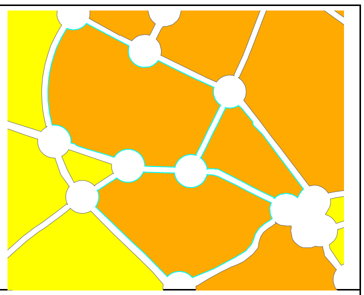
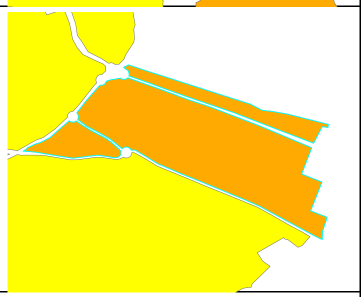
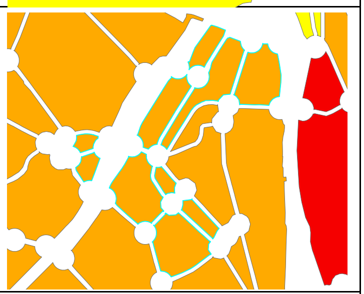
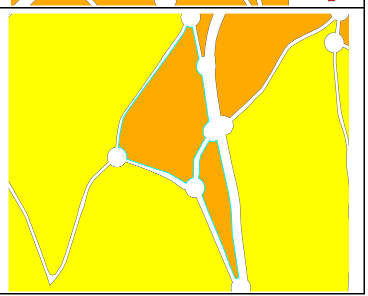
Source: Own research

Table 4 Residential areas

Ranking Without PDO	Ranking With PDO	ID	Section
1	2	53	
2	1	2	
3	3	54	
4	5	57	
5	7	8	
6	4	27	
7	9	25	
8	6	1	
9	10	36	
10	14	75	
11	8	19	

12	18	67	
13	11	11	
14	13	12	
15	20	5	
16	17	58	
17	16	24	

18	15	28	
19	-	38	
-	12	23	
-	19	33	

Source: Own research

A 8 Results of traffic-oriented roads

Table 5 Results of traffic-oriented roads without PDO

Ran-king	ID	Net length	ø AADT	Accidents 2009-13		ACD (FSI+MI+PDO)	baACD (FSI+MI+PDO)	InfraPo (FSI+MI+PDO)	avAC (FSI+MI+PDO)	Priority	Influential factors		
[-]	[-]	[m]	[veh/d]	A(FSI)	A(MI)	[1000 CHF/(a*km)]			[1000 CHF/a]		Accident type	Participation	Other
1	68	1'672	10'474	18	34	1'840.19	512.28	1'327.91	2'220	high	Collision	Bicycle	Distraction
2	29	1'218	2'100	12	24	1'702.46	102.71	1'599.75	1'948	high	Crossing	Tram	
3	10	855	9'579	11	29	2'360.70	468.51	1'892.19	1'618	high		Bicycle	
4	52	2'120	11'280	14	49	1'307.55	551.70	755.84	1'602	high	Crossing	Pedestrian	Right of way
5	98	996	10'630	9	47	2'050.60	519.91	1'530.69	1'525	high		Heavy traffic	
6	43	1'031	14'180	11	37	2'088.07	693.54	1'394.53	1'438	high	Crossing	Pedestrian	Right of way
7	38	1'080	9'901	11	23	1'775.56	484.26	1'291.30	1'395	medium	Crossing		Right of way
8	74	1'128	4'094	7	34	1'370.21	200.24	1'169.98	1'320	medium	Crossing	Pedestrian	Right of way
9	128	1'498	3'519	8	27	1'046.19	172.11	874.08	1'309	medium	Crossing	Pedestrian	
10	21	1'129	6'241	8	32	1'462.53	305.25	1'157.29	1'307	medium	Turn off	Tram	Right of way
11	20	797	18'924	8	49	2'430.11	925.57	1'504.54	1'199	medium	Crossing	Pedestrian	Distraction
12	108	935	11'656	10	16	1'776.26	570.09	1'206.16	1'128	medium	Collision		Distraction
13	18	924	3'895	6	21	1'285.71	190.50	1'095.21	1'012	medium	Turn off	Bicycle	Right of way
14	34	935	14'321	8	32	1'765.99	700.44	1'065.55	996	medium	Collision	Motorbike	Distraction
15	33	780	15'889	8	29	2'052.31	777.13	1'275.18	995	medium	Crossing	Pedestrian	
16	2	1'107	7'768	7	22	1'214.09	379.93	834.16	923	medium	Turn off	Bicycle	Right of way
17	6	1'207	3'393	6	16	914.66	165.95	748.71	904	medium	Crossing	Heavy traffic	
18	135	1'007	9'240	6	30	1'329.89	451.93	877.96	884	medium	Turn off		Distraction
19	16	687	5'358	5	17	1'428.82	262.06	1'166.76	802	medium	Driving accident	Tram	Right of way
20	36	1'274	6'878	6	22	945.68	336.40	609.28	776	medium	Turn off	Pedestrian	Distraction
21	37	1'212	4'507	6	11	841.58	220.44	621.15	753	medium	Driving accident	Bicycle	Distraction
22	19	500	3'798	4	16	1'651.20	185.76	1'465.44	733	medium	Crossing	Pedestrian	Distraction
23	23	1'651	13'950	8	44	1122.23	682.29	439.93	726	medium	Collision	Motorbike	Distraction

Source: Own research

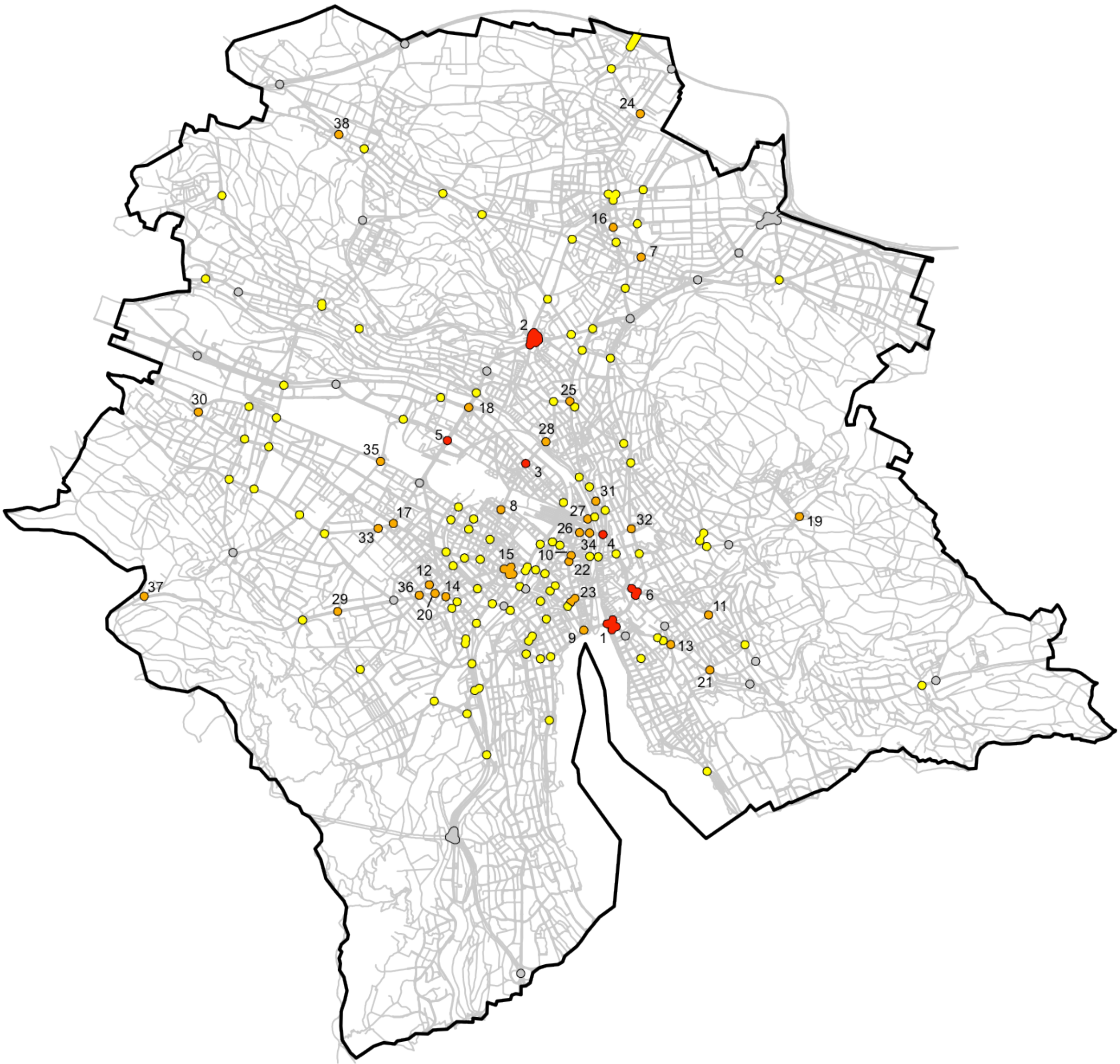
Table 6 Results of traffic-oriented roads with PDO

Ran-king	ID	Net length	ø AADT	Accidents 2009-13			ACD (FSI+MI+PDO)	baACD (FSI+MI+PDO)	InfraPo (FSI+MI+PDO)	avAC (FSI+MI+PDO)	Priority	Influential factors		
[-]	[-]	[m]	[veh/d]	FSI	MI	PDO	[1000 CHF/(a*km)]			[1000 CHF/a]		Accident type	Participation	Other
1	68	1672	10474	18	34	27	1'986.60	512.28	1'474.32	2'465	high	Driving accident	Bicycle	Distraction
2	43	1031	14180	11	37	78	2'770.03	693.54	2'076.49	2'141	high	Collision	Pedestrian	Right of way
3	29	1218	2100	12	24	20	1'851.23	102.71	1'748.52	2'130	high	Driving accident	Heavy traffic	Right of way
4	52	2120	11280	14	49	40	1'478.02	551.70	926.31	1'964	high	Turn off	Heavy traffic	Right of way
5	98	996	10630	9	47	47	2'476.20	519.91	1'956.29	1'948	high	Collision	Heavy traffic	Right of way
6	10	855	9579	11	29	30	2'677.78	468.51	2'209.27	1'889	high	Turn off	Heavy traffic	Distraction
7	21	1129	6241	8	32	52	1'877.77	305.25	1'572.52	1'775	high	Turn off	Heavy traffic	Right of way
8	20	797	18924	8	49	42	2'905.40	925.57	1'979.82	1'578	medium	Collision	Pedestrian	Distraction
9	38	1080	9901	11	23	18	1'926.57	484.26	1'442.32	1'558	medium	Crossing	Bicycle	Right of way
10	74	1128	4094	7	34	26	1'578.28	200.24	1'378.04	1'554	medium		Pedestrian	Right of way
11	128	1498	3519	8	27	18	1'154.87	172.11	982.76	1'472	medium	Crossing	Heavy traffic	Right of way
12	33	780	15889	8	29	41	2'526.41	777.13	1'749.28	1'364	medium	Collision	Heavy traffic	Distraction
13	108	935	11656	10	16	19	1'960.21	570.09	1'390.12	1'300	medium	Collision		Distraction
14	34	935	14321	8	32	33	2'084.49	700.44	1'384.05	1'294	medium	Collision	Heavy traffic	Distraction
15	18	924	3895	6	21	28	1'559.09	190.50	1'368.59	1'265	medium	Turn off	Heavy traffic	Disregard LSC
16	23	1651	13950	8	44	58	1'438.89	682.29	756.59	1'249	medium	Collision	Motorbike	Distraction
17	135	1007	9240	6	30	31	1'607.55	451.93	1'155.62	1'164	medium	Turn off	Heavy traffic	Right of way
18	6	1207	3393	6	16	20	1'064.29	165.95	898.34	1'084	medium	Turn off	Heavy traffic	Right of way
19	97	2021	12021	10	30	40	1'116.77	587.95	528.83	1'069	medium	Collision	Heavy traffic	Distraction
20	2	1107	7768	7	22	7	1'271.64	379.93	891.70	987	medium	Turn off	Bicycle	Right of way
21	110	663	11426	6	15	28	2'020.81	558.85	1'461.97	969	medium	Collision	Heavy traffic	Right of way
22	36	1274	6878	6	22	17	1'066.25	336.40	729.85	930	medium		Bicycle	Distraction
23	26	610	40784	7	40	55	3'511.64	1'994.75	1'516.89	925	medium	Collision	Heavy traffic	Distraction
24	16	687	5358	5	17	13	1'599.85	262.06	1'337.79	919	medium	Driving accident	Bicycle	Right of way
25	19	500	3798	4	16	20	2'012.00	185.76	1'826.24	913	medium			Alcohol suspicion
26	17	1016	7722	5	20	26	1'246.56	377.68	868.87	883	medium		Heavy traffic	Right of way

Source: Own research

A 9 Results of nodes

Figure 6 Ranking of the nodes whithout PDO (legend to Table 7)



Source: own research

Table 7 Results of the nodes without PDO

Ran-king	Name	Area	Inlets	ø AADT	Accidents 2009-13		avAC (FSI+MI+PDO)	Priority	Influential factors		
[-]	[-]	[m²]	[-]	[veh/d]	FSI	MI	[1000 CHF/a]		Accident type	Participation	Other
1	Bellevueplatz	58182	10	58182	10	40	1'878	high	Collision	Pedestrian	Distraction
2	Bucheggplatz	41912	8	41912	8	39	1'635	high	Collision	Bicycle	Distraction
3	Limmatplatz	22996	6	22996	6	18	1'079	high	Crossing	Pedestrian	Right of way
4	Central	30532	7	30532	7	12	1'078	high	Crossing	Pedestrian	Right of way
5	Pfingstweid-/ Hardstr.	57027	6	57027	6	18	1'028	high	Driving accident	Bicycle	Alcohol suspicion
6	Heimplatz	45400	5	45400	5	25	971	high	Crossing	Motorbike	
7	Dörfli-/ Schwamendingerstr.	21014	5	21014	5	17	941	medium	Turn off	Bicycle	Right of way
8	Militär-/ Langstr.	10731	5	10731	5	13	887	medium	Crossing	Pedestrian	
9	Bürkliplatz	49590	5	49590	5	14	804	medium	Collision	Pedestrian	Distraction
10	Sihl-/ Bahnhofstr.	11280	5	11280	5	4	742	medium	Crossing	Tram	
11	Römerhof	12193	4	12193	4	11	718	medium	Crossing	Bicycle	Right of way
12	Zwinglihaus	11296	4	11296	4	10	696	medium	Turn off		Disregard LSC
13	Kreuzplatz	23633	4	23633	4	8	631	medium		Motorbike	Distraction
14	Birmensdorfer-/ Zweierstr.	16886	3	16886	3	13	604	medium	Crossing	Pedestrian	Distraction
15	Stauffacher	25020	3	25020	3	16	591	medium	Crossing	Heavy traffic	
16	Sternen Oerlikon	1468	4	1468	4	2	587	medium	Crossing	Pedestrian	
17	Albisriederplatz	27104	3	27104	3	14	584	medium	Crossing	Pedestrian	Right of way
18	Escher-Wyss-Platz	75206	3	75206	3	21	530	medium	Crossing	Motorbike	
19	Dreiwiesen	16130	3	16130	3	7	504	medium	Turn off		Disregard LSC

Ran-king	Name	Area	Inlets	ø AADT	Accidents 2009-13		avAC (FSI+MI+PDO)	Priority	Influential factors		
20	Birmensdorfer-/ Aemtlerstr.	7833	3	14510	2	15	503	medium	Turn in	Bicycle	Right of way
21	Hegibachplatz	7833	3	22544	3	7	492	medium	Crossing		Right of way
22	Urania-/ Bahnhofstr.	7146	3	25314	3	7	487	medium	Crossing	Pedestrian	
23	Paradeplatz	12813	4	1252	3	4	482	medium	Crossing	Pedestrian	
24	Glatttal-/ Schaffhauserstr.	7833	3	20812	3	6	479	medium	Turn in	Bicycle	Right of way
25	Schaffhauserplatz	7682	5	18534	3	5	442	medium	Collision	Bicycle	
26	Bahnhofstr. / HB	7833	3	24478	2	12	433	medium	Crossing	Pedestrian	Distraction
27	Landesmuseum	7629	3	37893	3	5	429	medium	Collision	Motorbike	Distraction
28	Rousseau-/ Kornhausstr.	7833	3	28530	2	12	425	medium	Collision		Alcohol suspicion
29	Schaufenbergstr.	7833	3	18096	2	10	412	medium	Crossing	Heavy traffic	Disregard LSC
30	Farbhof	7833	3	21106	2	10	406	medium	Collision	Pedestrian	Right of way
31	Stampfenbachplatz	7833	3	13276	2	9	404	medium	Collision	Bicycle	Distraction
32	ETH/ Universitätsspital	7833	3	17328	3	1	401	medium		Heavy traffic	Right of way
33	Krematorium Sihlfeld	7833	3	15248	2	9	400	medium		Bicycle	Right of way
34	Bahnhofplatz	7833	4	45952	2	14	396	medium	Crossing	Tram	Distraction
35	Herdernstr.	7833	3	19855	2	9	392	medium	Collision		Distraction
36	Goldbrunnenplatz	7833	4	23420	2	10	387	medium	Crossing	Heavy traffic	
37	Albisrieder-/ Birmensdorferstr.	7833	3	16991	2	8	380	medium	Collision		
38	Furttal-/Wehntalerstr.	7833	3	26180	2	9	379	medium	Collision		Distraction

Source: Own research

Table 8 Results of nodes with PDO

Ranking	Name	Accidents 2009-13			$avAC_{(FSI+MI+PDO)}$	Priority	Influential factors		
[-]	[-]	A(FSI)	A(MI)	A(PDO)	[1000 CHF/a]		Accident type	Participation	Other
1	Bellevueplatz	10	40	85	2'644.18	high	Collision	Heavy traffic	Deflection
2	Bucheggplatz	8	39	52	2'103.74	high	Collision	Heavy traffic	Deflection
3	Heimplatz	5	25	110	1'961.50	high	Crossing	Heavy traffic	Right of way
4	Central	7	12	45	1'484.19	high	Crossing	Heavy traffic	Right of way
5	Limmatplatz	6	18	27	1'322.45	high	Crossing	Pedestrian	Right of way
6	Pfingstweid-/ Hardstr.	6	18	29	1'289.92	high	Driving accident	Bicycle	Deflection
7	Bürkliplatz	5	14	42	1'183.00	high	Collision	Heavy traffic	Deflection
8	Escher-Wyss-Platz	3	21	64	1'106.51	high	Crossing	Heavy traffic	Right of way
9	Militär-/ Langstr.	5	13	20	1'067.48	medium			
10	Dörfli-/ Schwamendingerstr.	5	17	13	1'058.83	medium			
11	Albisriederplatz	3	14	32	871.85	medium			
12	Landesmuseum	3	5	49	870.29	medium			
13	Stauffacher	3	16	27	833.81	medium			
14	Walcheplatz	2	9	52	829.87	medium			
15	Römerhof	4	11	12	826.64	medium			
16	Sihl-/ Bahnhofstr.	5	4	9	823.08	medium			
17	Kreuzplatz	4	8	17	784.22	medium			
18	Zwinglihaus	4	10	7	759.34	medium			

Ranking	Name	Accidents 2009-13			$avAC_{(FSI+MI+PDO)}$	Priority	Influential factors		
19	Glatttal-/ Schaffhauserstr.	3	6	23	685.82	medium			
20	Birmensdorfer-/ Zweierstr.	3	13	8	675.94	medium			
21	Bahnhofplatz	2	14	31	675.39	medium			
22	Bahnhofstr. / HB	2	12	26	667.29	medium			
23	Sihlbrücke	2	8	33	624.64	medium			
24	Sternen Oerlikon	4	2	2	605.05	medium			
25	Bleicherweg / Talstr.	2	8	24	587.00	medium			
26	Birmensdorfer-/ Aemtlerstr.	2	15	9	583.80	medium			
27	Hegibachplatz	3	7	10	582.30	medium			
28	Herdernstr.	2	9	21	580.75	medium			
29	Schimmel-/ Manessestr.	1	9	46	570.19	medium			
30	Zehntenhausplatz	2	7	27	566.04	medium			
31	Dreiwiesen	3	7	6	558.59	medium			
32	Urania-/ Bahnhofstr.	3	7	6	540.99	medium			
33	Sihlhölzli-/ Manessestr.	2	8	23	538.78	medium			
34	Farbhof	2	10	14	532.16	medium			
35	Bhf Oerlikon Ost	1	12	28	531.00	medium			
36	Goldbrunnenplatz	2	10	16	530.76	medium			
37	Rousseau-/ Kornhausstr.	2	12	10	515.53	medium			
38	Schaffhauser-/ Franklinstr.	2	4	21	512.04	medium			
39	Seebahn-/ Kalkbreitestr.	1	15	23	508.05	medium			
40	Schaffhauserplatz	3	5	7	505.71	medium			
41	Stampfenbachplatz	2	9	10	494.36	medium			
42	Paradeplatz	3	4	0	481.90	medium			
43	Milchbuck	3	6	12	480.03	medium			
44	Furttal-/Wehntalerstr.	2	9	11	478.63	medium			

Source: Own research

A 10 Results of residential areas

Table 9 Results of residential areas without PDO

Ranking	ID	Area	Net length	ø AADT	Accidents 2009-13		$ACD_{(FSI+MI)}$	Priority	Influential factors		
[-]	[-]	[m²]	[m]	[veh/d]	A(FSI)	A(MI)	[CHF/(a*km)]		Accident type	Participation	Other
1	53	974'433	655	-	5	9	1'293'435.11	high	Driving accident	Bicycle	Alcohol suspicion
2	2	244'013	806	-	3	17	872'456.58	high	Crossing	Pedestrian	Alcohol suspicion
3	54	381'954	1'091	-	4	11	679'743.35	high	Collision	Heavy traffic	Distraction
4	57	831'165	5'966	-	15	51	493'597.05	medium	Crossing	Bicycle	Right of way
5	8	311'999	2'566	-	7	15	477'942.32	medium	Crossing	Pedestrian	Distraction
6	27	306'930	4'786	-	10	51	469'870.46	medium	Crossing	Bicycle/Pedestrian	Right of way
7	25	291'871	1'773	-	4	9	399'323.18	medium	Frontal collision	Motorbike	
8	1	238'460	2'153	-	3	11	279'795.63	medium	Crossing	Pedestrian	Distraction
9	36	268'493	3'100	-	5	9	273'290.32	medium	Crossing	Bicycle	
10	75	662'898	3'274	-	5	10	263'897.37	medium	Crossing	Pedestrian	Alcohol suspicion
11	19	270'411	749	-	1	3	253'137.52	medium	Crossing	Pedestrian	Distraction
12	67	1'005'732	2'007	-	3	4	241'554.56	medium	Driving accident	Bicycle	Distraction
13	11	256'829	3'555	-	4	17	236'962.03	medium	Crossing	Motorbike/Pedestrian	Right of way
14	12	370'257	4'254	-	5	13	214'950.63	medium	Crossing	Bicycle	Right of way
15	5	263'145	3'252	-	4	7	207'380.07	medium		Bicycle	Right of way
16	58	706'633	4'155	-	4	18	206'787.00	medium	Crossing	Pedestrian	Distraction
17	24	269'337	3'841	-	4	13	201'822.44	medium	Collision	Pedestrian	
18	28	300'163	5'207	-	5	20	198'194.74	medium	Crossing	Bicycle	Alcohol suspicion
19	38	1'826'538	11'712	-	12	35	192'827.87	medium	Crossing	Bicycle	Distraction

Source: own research

Table 10 Results of residential areas with PDO

Ranking	ID	Area	Net length	Accidents 2009-13			$ACD_{(FSI+MI)}$	Priority	Influential factors (local)		
[-]	[-]	[m²]	[m]	A(FSI)	A(MI)	A(PDO)	[CHF/(a*km)]		Accident type	Participation	Other
1	2	244'013	806	3	17	69	1'643.30	high	Driving accident	Heavy traffic	Distraction
2	53	974'433	655	5	9	25	1'637.71	high	Driving accident	Heavy traffic	
3	54	381'954	1091	4	11	21	853.35	high	Driving accident	Heavy traffic	Distraction
4	27	306'930	4786	10	51	112	680.69	medium	Driving accident	Bicycle	Right of way
5	57	831'165	5966	15	51	95	637.16	medium	Driving accident	Bicycle	Right of way
6	1	238'460	2153	3	11	74	589.27	medium	Driving accident	Heavy traffic	Distraction
7	8	311'999	2566	7	15	23	558.89	medium	Driving accident	Pedestrian	Distraction
8	19	270'411	749	1	3	23	529.64	medium	Driving accident		
9	25	291'871	1773	4	9	17	485.84	medium	Driving accident	Motorbike	
10	36	268'493	3100	5	9	43	398.29	medium	Driving accident		Alcohol
11	11	256'829	3555	4	17	60	388.97	medium	Driving accident	Heavy traffic	Right of way
12	23	253'106	2110	1	10	51	363.18	medium	Driving accident	Heavy traffic	Distraction
13	12	370'257	4254	5	13	48	316.62	medium	Driving accident	Heavy traffic	Right of way
14	75	662'898	3274	5	10	19	316.28	medium	Driving accident	Heavy traffic	
15	28	300'163	5207	5	20	60	302.00	medium	Driving accident	Bicycle	Right of way
16	24	269'337	3841	4	13	34	281.59	medium	Driving accident	Heavy traffic	Distraction
17	58	706'633	4155	4	18	31	274.03	medium	Driving accident	Heavy traffic	Distraction
18	67	1'005'73	2007	3	4	5	264.13	medium	Driving accident	Bicycle	Distraction
19	33	270'296	1522	1	7	16	263.40	medium	Driving accident		Distraction
20	5	263'145	3252	4	7	16	251.78	medium	Driving accident	Heavy traffic	Right of way

Source: Own research

Table 11 Results of residential areas with PDO

Ranking	ID	...	Priority	Influential factors (global)		
[-]	[-]			Accident type	Participation	Other
1	2		high	Driving accident		Distraction
2	53		high		Heavy traffic	Right of way
3	54		high	Collision	Heavy traffic	Disregard LSC
4	27		medium	Crossing	Bicycle	Alcohol
5	57		medium	Collision	Bicycle	Right of way
6	1	...	medium	Driving accident	Heavy traffic	Distraction
7	8		medium	Crossing	Pedestrian	Distraction
8	19		medium	Driving accident	Pedestrian	Alcohol
9	25		medium		Motorbike	Alcohol
10	36		medium	Driving accident	Bicycle	Alcohol
11	11	...	medium	Crossing	Heavy traffic	Right of way
12	23		medium	Driving accident	Heavy traffic	Distraction
13	12		medium			Right of way
14	75		medium		Pedestrian	Alcohol
15	28		medium	Frontal collision	Bicycle	Right of way
16	24		medium	Driving accident	Bicycle	Right of way
17	58		medium			
18	67	...	medium	Collision	Bicycle	Distraction
19	33		medium	Collision	Bicycle	Distraction
20	5		medium	Crossing		Right of way

Source: Own research