NTNU
Norwegian University of
Science and Technology

Application of GIS Methodologies in Traffic Safety

The Case Study of Singsaker School

Alejandro Garcia-Torres Fernandez

Civil and Environmental Engineering
Submission date: June 2017
Supervisor: Thomas Jonsson, IBM

Norwegian University of Science and Technology
Department of Civil and Environmental Engineering

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Report Title: Application of GIS Methodologies in Traffic Safety: The Case Study of Singsaker School	Date:07/06/2017 Number of pages (incl. appendices):			
	Master Thesis	X	Project Work	
Name: Alejandro García-Torres Fernández				
Professor in charge/supervisor: Thomas Jonsson				
Other external professional contacts/supervisors: Eirin Ryeng				

Abstract:

This research investigates the feeling of insecurity that parents have regarding their children's journeys to school. Parents, professors, and many other professionals were included in a survey to rate the different features that children might encounter when walking along and crossing the streets on their routes to school. By giving the street network an impedance attribute known as "insecurity" with regards to the issue of motorized traffic and street infrastructure, the idea is to assess the accessibility from children's homes to school from this different viewpoint. Using "feeling of insecurity" during accessibility analysis, planners and engineers can assess the school environment when identifying dangerous locations or areas that require improvement.

The methodology used to rate streets is the utilization of a stated-preference survey followed by a Multi Criteria Analysis (MCA) and Analysis Hierarchy Process (AHP).Moreover, this research presents one particular method for developing an accurate street network, representing where pedestrians can walk and cross the street, from a dataset containing the "center line" of a street network (typically designed for motorized vehicles). Once the street network is created, the attributes required for such a network to perform the analysis are presented and also the source of the data used when populating each attribute.

The original idea of a "traffic safety impedance" comes from the Federal Highway Administration of Washington DC (FHWA), which developed a methodology to rate streets and crossings according to different parameters. This methodology is modified in this research and is combined with a Multicriteria Analysis (MCA) and Analysis Hierarchy Process (AHP) to perform an analysis based on a subjective perception of insecurity experienced on streets. The model will look for streets with width sidewalks, also separation of motorized traffic and vulnerable road users, and finally low speed limit and traffic flow. On the contrary, this model will avoid busy intersections or streets with higher speed limit and heavy traffic volume.

Finally, a case study is performed which applies all the methodology presented here in order to demonstrate a real life case where such methodology might be of use. The case study uses one primary school in the city of Trondheim (Norway), creating a pedestrian network within the school boundary, and performing an analysis that attempts to identify problematic locations where traffic safety measures may be necessary. This research aims to present a useful tool for assessing children's traffic safety and could be used along with traffic safety audits.

Keywords:

1. Traffic Safety
2. Pedestrian/Children Accessibility
3. Safe Routes to School Programs
4. Geographic Information System (GIS)

ACKNOWLEDGEMENTS

This thesis is the result of a lengthy period of research during which I have had the chance to learn a great deal about cities, pedestrians, mobility, and traffic safety issues. I have experienced long and demanding nights of interminable work and have also encountered unexpected obstacles along the route which I had to overcome myself by taking sometimes risky decisions. However, once the work is finally done, one takes a retrospective view of how it all started and it is only now when you realize where you are, how much you have learnt, and how many people you have encountered along the way.

Because this Master's Thesis involves many different fields of Civil and Transport Engineering, and also other disciplines such as Urban Planning, I have had the chance to hold conversations with highly skilled professionals who have always been very hospitable and willing to collaborate, and therefore I would like to thank:

Inge Hoff, Professor at the Civil and Transport Engineering Department, because he was the first person I contacted one year ago regarding writing my thesis at NTNU. He made the department accessible to me and assisted me in finding a supervisor.

Eirin Ryeng, Associate Professor at the Civil and Transport Engineering Department, for accepting me onto the Master's Thesis program as an exchange student, for inspiring in me a new perspective regarding sustainable transport issues during her lectures, and for introducing me to my supervisor, Thomas Jonsson.

Thomas Jonsson, Professor at the Civil and Transport Engineering Department, for his understanding and support throughout this period, for his willingness to collaborate with international students, for his vast knowledge of the field of Traffic Safety (especially regarding pedestrians and cyclist issues), and for his recommendations which helped me to refine my thesis.

Yngve Karl Frøyen, Professor at the Urban Planning Department, for providing me with many kinds of vectorial data needed to perform analysis in networks for pedestrians and cyclists, datasets from land planning, and finally for his recommendations in network analysis, Trond Arve Haakonsen and Jensen Jan Kristian, from The Norwegian Public Roads Administration (NPRA), for providing me with access to this institution, for helping me with ortophoto datasets and also for introducing me to the Norwegian Road Dataset Bank (NVDB) which was of outstanding help when writing my thesis as it contained almost all of the data I required.

Terje Midtbø , Erlend Oskar Wold, Gravaas Bente Christine, Line Langorgen and Wenche Stinessen, from the Trondheim Kommune, for giving me support and providing research projects related to children's routes to school within the city of Trondheim, and Relling Svein Åge, also from Trondheim Kommune, who assisted me with datasets of the city and recommendations on how to build a network for pedestrians.

Peter Ashby-Saracen, Private English Teacher, who has been proof-reading my Master's Thesis throughout this period, suggesting more accurate translations and expressions to me in order to improve the style of English used, for his patience when reading the lengthy chapters of this project, and for the last week of May when I pushed him to the limits.

Liliya Zhupanova, Research Assistant at the Civil and Transport Engineering Department, for helping me during the frenetic final week with last-minute recommendations on how to properly build the final layout, and for helping me to submit my Master's Thesis correctly.

And last but not least, I wish to avoid making the mistake of forgetting every single person involved in this research and therefore, I would like to thank the Department of Civil and Transport Engineering and all of those people not mentioned above, who were very close to me during this long journey, helping and greatly encouraging me in various ways to make this modest project finally reach fruition.

To all of them, thank you very much, it has been a pleasure.

Alejandro García-Torres Fernandez

SUMMARY

Keywords: pedestrian, children, parents, school, route planning, GIS, network, traffic safety, feeling of insecurity, traffic safety measures, accessibility, mobility, multicriteria analysis, subjective perception, urban planning, safe routes to school program

This research investigates the feeling of insecurity that parents have regarding their children's journeys to school. Parents, professors, and many other professionals were included in a survey to rate the different features that children might encounter when walking along and crossing the streets on their routes to school. By giving the street network an impedance attribute known as "insecurity" with regards to the issue of motorized traffic and street infrastructure, the idea is to assess the accessibility from children's homes to school from this different viewpoint. Using "feeling of insecurity" during accessibility analysis, planners and engineers can assess the school environment when identifying dangerous locations or areas that require improvement.

The methodology used to rate streets is the utilization of a stated-preference survey followed by a Multi Criteria Analysis (MCA) and Analysis Hierarchy Process (AHP).Moreover, this research presents one particular method for developing an accurate street network, representing where pedestrians can walk and cross the street, from a dataset containing the "center line" of a street network (typically designed for motorized vehicles). Once the street network is created, the attributes required for such a network to perform the analysis are presented and also the source of the data used when populating each attribute.

The original idea of a "traffic safety impedance" comes from the Federal Highway Administration of Washington DC (FHWA), which developed a methodology to rate streets and crossings according to different parameters. This methodology is modified in this research and is combined with a Multicriteria Analysis (MCA) and Analysis Hierarchy Process (AHP) to perform an analysis based on a subjective perception of insecurity experienced on streets. The model will look for streets with width sidewalks, also separation of motorized traffic and vulnerable road users, and finally low speed limit and traffic flow. On the contrary, this model will avoid busy intersections or streets with higher speed limit and heavy traffic volume.

Finally, a case study is performed which applies all the methodology presented here in order to demonstrate a real life case where such methodology might be of use. The case study uses one primary school in the city of Trondheim (Norway), creating a pedestrian network within the school boundary, and performing an analysis that attempts to identify problematic locations where traffic safety measures may be necessary. This research aims to present a useful tool for assessing children's traffic safety and could be used along with traffic safety audits.

Content

List of Figures:

CHAPTER I:

INTRODUCTION

I) INTRODUCTION

1- BACKGROUND

This section will commence with an introduction to Safe Routes to School Programs that will help us to understand this issue more clearly:

"SRTS programs use a variety of education, engineering and enforcement strategies that help make routes safer for children to walk and cycle to school, and encouragement strategies to entice more children to walk and cycle. They have become popular in recent years in response to problems created by an expanding built environment, a growing reliance on motor vehicles for student transportation and with the more recent development of federal and state funding of SRTS programs.

Each school starts from a unique situation and with different circumstances. Some schools have great places for walking and cycling but few students are taking advantage of them. Other communities have children walking and cycling to school in unsafe conditions or along poorly maintained routes, while some communities do not have children walking or cycling to school at all. Successful SRTS programs involve the whole community. Parents, children, neighborhood groups, schools, law enforcement officers, community leaders, and transportation and public health professionals help identify the issues and solutions.

The implications of SRTS can be far-reaching. SRTS programs can improve safety, not just for children, but for a community of pedestrians and cyclists. They provide opportunities for people to become more physically active and to rely less on their motor vehicles. SRTS programs benefit the environment and a community's quality of life by reducing traffic congestion and motor vehicle emissions.

For communities concerned about traffic jams, unsafe walking conditions, physically inactive lifestyles and overall quality of life, SRTS programs can be an effective starting point for tackling these issues."

(Brown et al., 2015)

This guidebook also indicates the key elements necessary in order to succeed with Safe Routes to School Programs. The situation of each school may be different and may present features specific to itself, but five basic elements can always be identified:

- Education: Teaching parents, neighbors, drivers and student about how to walk and cycle safely with the benefits that it includes.
- Encouragement: Encouraging all the involved parties into walking and cycling safely to school.
- Enforcement: Improving law awareness and enforcement with the aim of changing driver behavior.
- Engineering: City and transport planners has the capability of building the environment where it is safer to walk or cycle with the help of safety tools.

Therefore, we will set out the foundations of a Master's Thesis *(Application of GIS Methodologies in Traffic Safety: The Case Study of Singsaker School)* within the scope previously introduced. GIS software will be our main ally in this project, combining useful tools within the field of Urban Planning and Traffic Safety, which are intrinsically connected with each other.

2- STATE OF ART (LITERATURE REVIEW)

GIS software has the potential to become an exceptionally useful tool for handling spatial and statistical data within the field of traffic safety. We are as yet some way from a standardized framework involving both the collaboration of local government and public participation, but there has been some important research conducted on this matter. This review presents several studies that have analyzed children's mode of travel choice to and from school, and another which has used a geographic information system when analyzing the routes that children take on the journey to school. Following this we will consider a pioneer study that presents a framework for data collection as well as a guidebook for safe routes to school:

A study conducted in Malaysia in 2014 aimed to gain insight into the safety route parameter for children for walking and cycling to school (Aziz et al., 2014) using for this purpose a Geographic Information System (GIS). Parameters such as distance, traffic situation and mobility were studied in order to create a complete picture of this issue. Children living outside the walking distance to a school tend to choose their parents' car as their preferred method of travel, although this might vary depending on the location of the school. The shortest routes to and from school seem to be more unsafe when they pass through several critical junctions, so this might influence the chosen mode of travel. One study that attempts to understand environmental correlates related with route choice compared features between the actual route and the shortest route to and from school on foot or by cycling (Dessing et al., 2016)**.** The results suggest that children try to avoid roads with higher volumes of traffic, resulting in a slightly longer journey.

More studies have investigated the comparison between the shortest routes and the actual routes using both GIS and GPS software as there might be some variations between these two. In one study conducted in 2014 at the University of Cambridge, the results show differences between them when commuting to and from school (Harrison et al., 2014) especially when comparing villages with urban areas. Another University of Cambridge study conducted in the same year shows that cyclists also choose cycleways or special lanes rather than the shortest route along main roads with complicated crossings (Krenn et al., 2014)**.** Another study suggests that there is a difference in the behavior of cyclists depending on whether they cycle along major routes or not (Aultman-Hall et al., 1997).

Some other studies have considered the parameters that most influence children's choice of travel mode. A study conducted in 2011 for the University of Toronto and Ontario (Larsen et al., 2012) examined environmental influences on children's choices. Distance, gender, income, road appearance, junctions, and traffic situation were analyzed. The results showed distance as the most important parameter, and some authors identify a "splitting line" of 2 km between the alternative modes of walking and motorized or transit travel (Kelly and Fu, 2014). It seems that above this line children almost never walk to and from school.

Another study conducted in 2010 in the United Kingdom (Panter et al., 2010) states also that elements in the surrounding neighborhood such as density of roads and streetlights, might also influence whether children choose to walk or cycle to and from school. In this case, distance seems not to be a decisive parameter in a specific neighborhood when choosing to walk or to cycle.

Parents also play a crucial role when it comes to choosing the way their children travel to and from school. In one study, parents were tasked with auditing street routes to seven elementary schools (Evers et al., 2014). They demonstrated concern regarding streets with deteriorated sidewalks or no sidewalk at all, intersections and high levels of traffic. Other research indicates that the concerns of parents might influence their children's choice (Larsen et al., 2013). Children's perception of an area as safe might result in them being more likely to walk. Furthermore, awareness about strangers and busy streets influences the mode of travel. Similarly, another work also points out that security in terms of crime and traffic is also related to the mode of travel that parents choose for their children (Nasrudin and Nor, 2013).

One study conducted in 2005 involved an ambitious project regarding school area safety in which 19 schools were analyzed. As a result, suggested safe walking routes were provided in order to improve safety in school areas. (Yee et al., 2007). Another study conducted in 2010 analyzed the urban environment form in terms of walkability impact, concluding that at the urban design level, the layout of street networks such as blocks and buildings should be taken into account in order to support safe pedestrian circulation with good permeability, connectivity and accessibility throughout the neighborhood (Ilir et al., 2010).

Surveys have been used to encourage children and parents to participate actively, combined with routes drawn by children on a computer, as one study did in 1996 (Austin et al., 1997). However, accurate data collection is crucial in order to obtain reliable results in a spatial and statistical analysis. In April 2013, in Texas, a diverse group of 15 GIS experts met to discuss the issue and as a result, one report presented two main ideas: a national storage database and a standard list of datasets. This created the foundation for a future standardized framework for using GIS for safe routes to school. Within this framework, three broad categories of data would be collected: monitoring travel, travel behavior, and routes. One of the first and most important steps is to undertake an assessment of the current landscape, and GIS can show where students are currently walking, locations of existing sidewalks and areas that lack pavements. In addition, it can also map out one-kilometer or two-kilometer buffers around schools to ascertain if and where students are likely to walk and cycle to school. Finally, gathering information on where students live can be one of the most important and challenging steps in Safe Routes to School data collection. (Issidro et al., 2013).

The Pedestrian and Bicycle Information Centre of the University of North Carolina and the Highway Safety Research Centre with support from the National Highway Transportation Safety Administration, Federal Highway Administration, Centers for Disease Control and Prevention and the Institute of Transportation Engineers developed a guidebook in order to address issues that can improve the built environment to enable children to safely walk and cycle to school. These include creating school walking and cycling route maps using a variety of assessment tools and exercises, identifying and regulating the school zone, providing and maintaining bicycle and pedestrian facilities along the school route including sidewalks, providing on-street bicycle facilities, paths, bridges and tunnels, providing safe street crossings for cyclists and pedestrians, and reducing traffic speed (Brown et al., 2015)

One report from 2012 in the city of Trondheim provides an overview of locations and parts of routes that parent's committees and schools define as having hazardous traffic within their school district. This report includes a list of suggestions that have been proposed from the individual school/FAU in each school district. The school journey report is a working document that provides an overview of unsafe points and areas within each school district. (Kommune, 2012).

Walkability is closely related to the pedestrian's route on their journey to work or school or to engage in leisure activities. A study conducted in 2011 as a Master's Thesis (Ballester, 2011) investigates the walkability perception of all pedestrians (concerning universal mobility) and how to evaluate their perceptions via a multicriteria analysis. This research also analyses the existing need for pedestrian networks and their limited availability.

3- RESEARCH QUESTIONS

We are now going to introduce the research questions that the thesis will attempt to answer.

3.1- What is the accessibility of the school?

We will first study the school within the urban form of the city of Trondheim. We wish to know how much time a child spends walking from their home to school using the classical approach of accessibility (in terms of distance) and we will indicate this on a map.

However, we will also introduce an innovative idea which calculates accessibility from another point of view, which is in terms of the "feeling of insecurity".

3.2- What are the shortest routes?

We will calculate all of the routes from each residential building to school, using for this purpose the walking time or distance. This will give us the shortest routes for each building.

Following this, we will identify "corridors", which are intended to inform us about which streets are more likely to be walked when looking for the shortest route.

3.3- What are the routes with the lowest feeling of insecurity?

In this instance, instead of resolving routes by using the walking time, we will use the attribute "Feeling of Insecurity" which is explained in more detail in the following sections.

Again, after calculating each single route from each building we will identify "corridors" which in this case are intended to inform us of those streets that are more likely to be walked when looking for a safer path.

3.4- What are the preferred routes by pedestrian/bikes?

Preferred routes are those routes actually walked by children on their journey to school. Children from the 5th year in primary school will manually draw on a map the route they walk from home to school and will also indicate where they feel safe or unsafe.

3.5- <u>How different are all these types of routes?</u>

We will attempt to indicate the difference between the shortest routes and the routes with the lowest feeling of insecurity. Here, we clearly have two extreme values. If both types of route differ greatly, it suggests that somehow pedestrians do not feel safe on their local streets and are therefore trying to avoid hazardous situations.

On the other hand, if both types of route are broadly similar, it means that the street network meets their needs and therefore pedestrians are travelling in the best conditions that the street network is able to provide.

3.6- <u>Which countermeasures could improve the feeling of insecurity on streets?</u>

By utilizing all of the information from the previous research questions we will suggest some countermeasures that might decrease the level of insecurity in terms of traffic. They might also increase traffic safety in the affected streets but this would have to be assessed properly.

4- METHOD

4.1- Introduction:

The number of schools to be studied will be mainly limited by time and human resources. The original idea was to study between 2-4 schools in the city of Trondheim. The locations would vary with the purpose of finding and comparing features between different environments (e.g. between the city center and the suburbs). However, because of the limited time available for completion and the amount of data to be collected, only one school has therefore been included in the study *(Chapter V: The Case Study of Singsaker School)*.

Parents will be given information via the school about study goals and procedures, and they will provide informed consent for their children. The municipality of Trondheim will be consulted as well in order to obtain their approval. A copy of the information letter can be found in *Appendix 1A – Information Letter*

Trondheim Kommune has been requested to provide any previous work regarding Safe Routes to School Programs. As a result, one report compiled in December 2012 was provided. This paper presents an overview of unsafe locations and routes within each school district. In autumn 2010, letters were sent out to all primary schools in Trondheim in which the Trondheim Kommune was asked for input and an update of the problems encountered en-route to school (Kommune, 2012).. Trondheim Kommune also collaborated with another document that showed children's routes to school on an unprocessed map (one which does not include vectorial data (Kommune, 2013). This document will be used for further analysis regarding route comparison.

School districts may change during the planning period as a result of development and urban growth of the nearby areas. This can result in new congestion problems and dangerous intersections. A continuous and close cooperation with the school and parent councils are both very important in order to obtain satisfactory results. Several schools have worked actively in improving measures for students, teachers and parents. However, efforts to ensure traffic safety on the journey to school will always be ongoing and need to be updated continuously.

From now on, when we refer to *Safe Routes to School Guidebook* (Brown et al., 2015) we will refer to SRTSG.

4.2- Methodology

4.2.1- Schools identified for study

According to SRTSG the very first step is to decide which schools to study. A preliminary study will set a buffer distance of 2km around the school as the central point, identifying within this distance the accidents which have occurred in the last 5-10 years (fatalities and injuries), and traffic data. This preliminary study will help to decide which schools we should initially focus on. We will take into account only those accidents involving both pedestrians and cyclists and at least one vehicle.

Different distance would be considered:

- School environment: This includes the school enrolment boundary, the school walk-zone and the school zone.
- School enrolment boundary: The entire zone around the school from which students are drawn.
- School walkzone: A buffer distance of typically 2km with the school as the central point
- School zone: The roadway immediately adjacent to the school.

Having chosen the 2-4 schools to study, it will be necessary to create an inventory within the walkable distance which includes information such as:

- Infrastructure within de school zone.
- The physical environment where children walk or bicycle to school.
- School zone signing and marking.
- Existing conditions map.

4.2.2- School walking routes

In accordance with the recommendations made by SRTSG the procedure will be as follows:

- Mapping: Students will be asked to draw their routes on a map of their school's catchment area, creating maps with the most popular routes. In cases where it is not possible for children to undertake this task, local institutions will be requested to collaborate by providing any relevant information.

- Observing**:** Data will be collected for each mapped route using the database of the Norwegian Public Roads Administration (NPRA) but also by conducting walkabouts within the school boundary in order to fill those datasets which lack information and to gather data currently not available.

As examples, we can indicate the following:

  - Street features: Width, furniture zone, curb zone…
  - Additional lanes: Both separate lanes and those integrated within the carriageway.
  - Hidden paths: Those paths through open field that do not appear on official datasets
  - Connectivity: Analyzing how the street network is connected with focal points.
  - Analyzing traffic: Traffic data will be analyzed within the school area. Data will be obtained from NPRA database.
  - Surveying: Schools and parents will be surveyed during the study. The survey will be presented on a temporary web and it will be available in three languages (English, Spanish and Norwegian).

4.2.3- Increasing the feeling of security

Several measures that may, if implemented, improve pedestrian's sense of security while walking along streets will be examined. Not all of them would be applied, but among them the more convenient ones will be considered.

These measures are explained in more detail in SRTSG (Section 3 – Engineering), and this subject is presented in greater depth in *Chapter V: The Case Study of Singsaker School.*

4.3- Data collection

Several methods are available for obtaining the routes that children take to school. Here we present the three methods considered in this project. Only one out of these three will finally be adopted.

4.3.1- Method 1: GPS

This method reproduces the methodology followed by a study conducted in 2016 in Amsterdam where 184 children were equipped with GPS devices. Walking and cycling routes to school were measured in order to compare them with the shortest possible route. (Dessing et al., 2016).

Children will be requested to wear a GPS device (model yet to be chosen) when walking to school, for 6-9 days. GPS will record geographical information about children's routes to school. The devices are provided at school and will be attached to the children's belts. Previous verbal instruction is given to both parents and children as well as written instructions. The children will finally be surveyed to gather information about gender, age and physical activity. Out of the total number of participants, children who have at least one recorded journey between school and home will be included in the study.

GPS data will be downloaded and handled using suitable software such as ArcGIS v9.3, v10.1, or URBIS. Walking and cycling will be included separately, setting a maximum speed limit for walking (<10 Km/h) and for cycling (<25 km/h). All the information will be converted into vectorial data and will be integrated in the Street Network.

4.3.2- Method 2: Online Mapping

There are many tools with which children´s routes can be drawn onto an online map giving the user the option of manually drawing the route, and then saving and sharing it. There is no need to download any software at all: all that is required is an Internet connection.

One of the following web applications will be used for mapping the routes:

- ArcGIS Online application
- Google Maps Maker
- Maptive

In this instance, children will be requested to draw their routes on a computer within school hours. Children will be divided into groups of 10-15 so that individual feedback can be provided. The children will finally be surveyed to gather information about gender, age and physical activity. When all the routes are documented, they will be transferred manually to GIS software to facilitate working with vectorial data.

4.3.3- Method 3: Manual Mapping

This procedure differs from the previous one in that the data will be collected from paper mapping. Children will be requested to draw their routes to school on a map. Again, children will be divided into groups of 10-15 so that individual feedback can be provided. Children will finally be surveyed to gather information about gender, age and physical activity. When all the routes are documented, they will be transferred manually to GIS software to facilitate working with vectorial data.

5- RESEARCH STRUCTURE AND WORKPLAN

5.1- Report Structure

This sections aims to give an overview on how the document should be read. First of all, it must be mentioned that this document contains many figures, tables and maps to facilitate the reader's understanding during the reading and evaluation process.

Of particular mention are the maps included in the ***Map Set Appendix***, which are intended to be printed on A3 format paper to better appreciate the details. Therefore, when reading and evaluating the document it is recommended to have a copy of this appendix at hand so that the maps be visualized in a much higher and more detailed resolution: otherwise, small details might not be appreciated in depth.

We will now introduce each chapter and provide a brief introduction to each one. This study project is composed of a total of five chapters, in addition to the corresponding appendix.

In *Chapter I: Background and State of Art*, we briefly introduce the overall issue of schools, children and the street network. A literature review is used to update this research with regards to traffic safety and GIS methodologies, and also regarding where parents and children express most concern on their journey to school. Finally, the methodology for data collection is presented.

Chapter II: Streets and Pedestrians crossings – Definition and classification sets out the regulations and standards required in order to establish the criteria for classifying and rating all the streets and pedestrian crossings within the street network. It also includes a brief introduction to street network hierarchy and characteristics.

Chapter III: Building the Street Network introduces the reader to the process of building a suitable street network, representing where pedestrians can walk and where they can cross a street, and explains how this has been constructed using ArcGIS. In addition, this chapter includes a number of basic definitions regarding Geographic Information System to help the reader interpret the following chapters.

Chapter IV: Feeling of Insecurity Impedance Methodology In this chapter, we present the original impedance methodology developed by the Federation Highway Administration of Washington D.C. (FHWA) on which this new methodology will be based. This chapter explains all the factors considered as well as the formulas that will be used on the street network to calculate the impedance attribute in terms of insecurity.

In *Chapter V: The Study Case of Singsaker School*, we make use of all the previous chapters in order to assess a real case for which we have chosen a primary school within the neighborhood of Singsaker in the city of Trondheim (Sør-Trøndelag, Norway). This chapter concludes by giving some recommendations on where measures that might increase the feeling of security on streets and pedestrian crossings could be implemented.

And finally, *Chapter VI: Conclusions, Discussion and Recommendations.* After analyzing the results, we briefly present the most important conclusions, we also discuss matters that the reader might have already thought about, and we conclude giving some recommendations for future research.

5.2- Workplan

Here, we briefly present the work plan that will be followed from January 2016 to May 2017 (*Next page):*

PACKAGE 1 – JAN 2017	PACKAGE 2 – FEB 2017	PACKAGE 3 – MARCH 2017
DATA COLLECTION	**SCHOOL SURVEYING**	**BUILDING ENVIRONMENT OF THE SCHOOL AREA**
<u>Communication</u>: - Trondheim Kommune - Vegvesen NPRA - Civil and Transport Engineering Department - Urban Planning Department <u>Gathering Data:</u> - Vectorial Data/Maps - Statistical Data - Traffic/Road Data - Road Network - Ortophotos	<u>School Selection</u> <u>School Contact</u> - Permission - Authorization <u>Mapping Routes</u> - From School - To School <u>Surveying Parents/Students</u>	<u>School environment</u>: - Enrolment - Walkzone - School zone - Existing Condition Map - Signing/Marking Map <u>Along the Route</u> - Universal Design - Streets/Sidewalks - Connectivity <u>Crossing the Street</u> - Universal Design - Crosswalks
PACKAGE 4 – APRIL 2017	**PACKAGE 5 – MAY 2017**	
GIS ANALYSIS	**FINAL REPORT**	
<u>Building convenient network around schools</u> - Lowest insecurity routes - Shortest routes - Actual routes <u>School within the Urban Form</u> - Accessibility - Closeness	<u>Research Questions</u> <u>Measures to Improve Traffic Safety</u> - Traffic Plan - Around the School - Along the route - Crosswalks <u>Conclusions</u>	

Table 1 – Workplan

CHAPTER II:

Streets And Pedestrian Crossings – Definition and Classification

II)STREETS AND PEDESTRIAN CROSSINGS – DEFINITION AND CLASSIFICATION

1- STREET CLASSIFICATION AND DEFINITION

For this first section we are going to refer to two main sources of information: Complete Street Design Guidelines (Burtt et al., 2013) and Design Manual for Urban Streets (Lahart et al., 2014)

According to Burtt: *"Street design is a key determinant in a community's livability. Streets are the public spaces that connect our homes, schools, businesses, civic buildings, recreation areas, daily necessities, and virtually all other destinations. They form the great majority of the circulation system. Streets provide access but they also define a sense of place, individual neighborhoods, and ultimately the community"* (Burtt et al., 2013).

Taylor claims that "*The desire for safe, attractive and vibrant streets is reflected in a range of existing transport, planning and environmental policies and objectives. These policies and objectives address how neighborhoods, villages and towns are created and protected. They relate not only to road safety and civil engineering, but also to town planning, urban design, architecture, landscape architecture and conservation"* (Lahart et al., 2014).

It is really important to design streets that meet the need of all modes of traffic and that the street fits into its context.

To achieve this, it will be crucial to develop well-defined associations between the physical design and the desired traffic operations of the street with regard to schools and traffic safety, the street network is of particular interest.

Schools should be surrounded by streets with a suitable hierarchy and infrastructure to provide a platform that encourages children to walk and bike to school within acceptable parameters of comfort, safety and security. The better defined the street network, the more desirable it will be to walk and cycle there.

1.1- Street Hierarchy

Street hierarchy varies from one country to another as it is closely related to the context of the urban form and therefore it is difficult to find a universal classification in which all cities and towns are included. As a consequence, street hierarchy should be considered at a local level.

Keeping this constraint in mind, streets and roads all over the world have similar characteristics according to the function they serve. In general, there are three levels in every street system:

- Arterial Streets: Multiple lane traffic facilities that carry large volumes of traffic usually at high speeds and connecting different centers/nodes or towns.
- Link Streets (Cross-town streets): These streets provide movement through the city by connecting neighborhoods and giving access to highways or major roads.
- Local streets: The shortest and the narrowest streets giving access to residential areas, schools and parks with low traffic volume and often very low speed limits.

Urban roads and streets might traverse areas with very different characteristics (commercial, industrial, residential, schools) and therefore they should be designed accordingly within each context. In general, the status of a street will be elevated when density and land use are higher, resulting in more activity. We could briefly classify the context as follows:

- Centre: The focus of economic and cultural activity. High pedestrian activity.
- Neighborhood: Medium/high density of housing with a broad mix of uses. Pedestrian activities ranges from high to moderate levels.
- Suburb: Lower density housing over expansive areas. Lower levels of pedestrians.
- Business Park/Industrial Estate: Areas of commercial and industrial activity outside city centers. Pedestrian activity might be high.

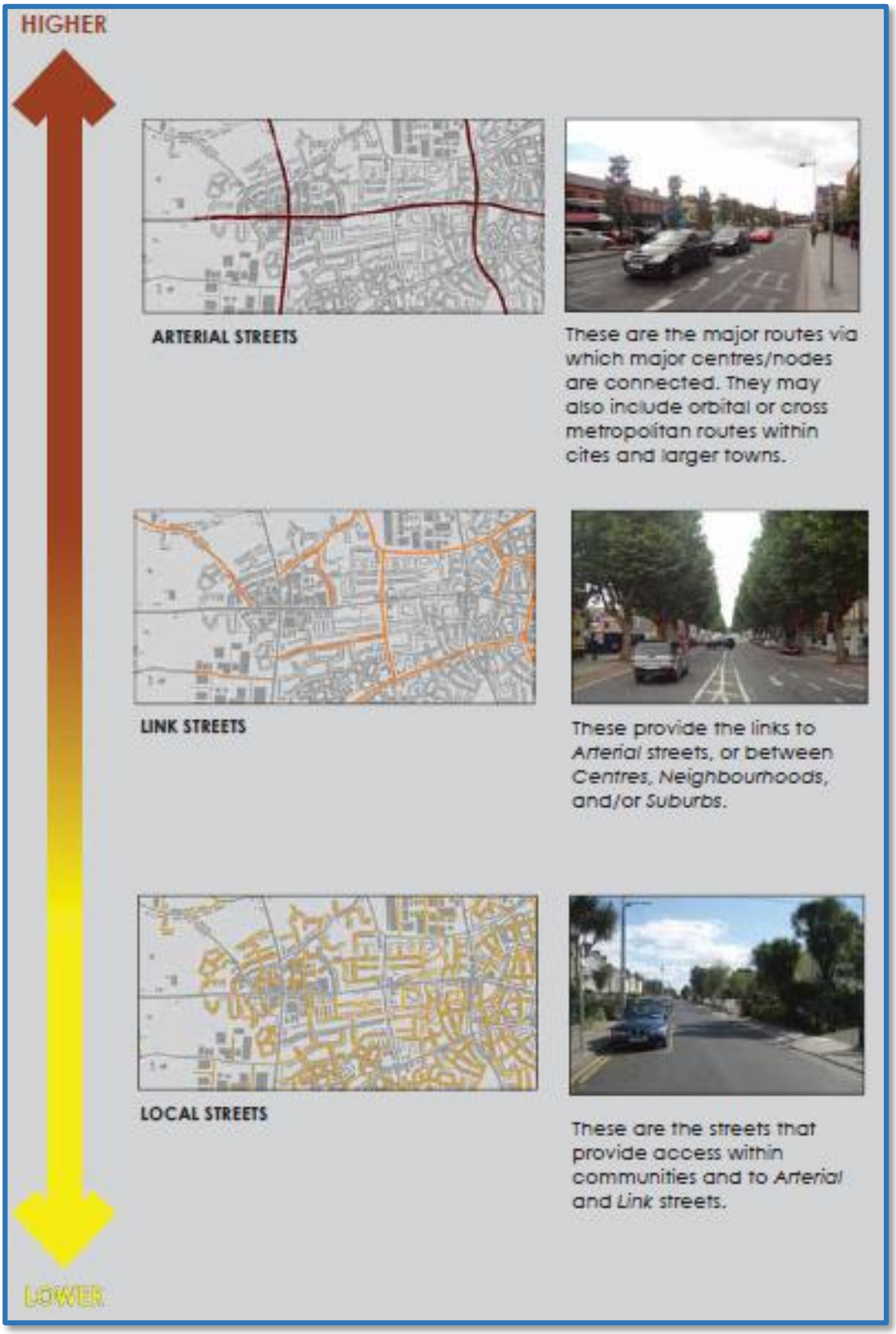


Figure 1 - Street Classification (Lahart et al., 2014)

-

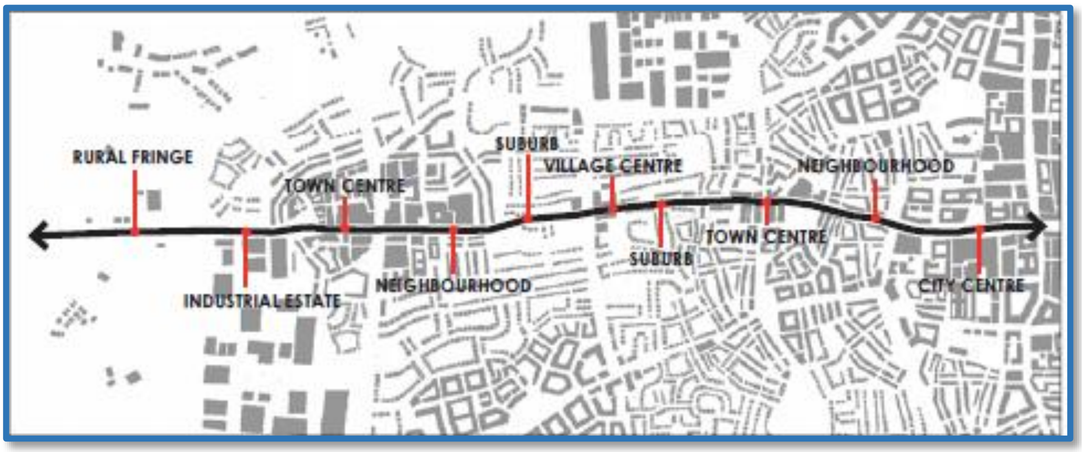


Figure 2 - Street Context (Lahart et al., 2014)

Figure 3 – Centers, neighborhoods, suburbs and business parks (Lahart et al., 2014)

Schools should be placed in streets with good accessibility and connectivity for all children, giving them a high degree of walkability. However, at the same time they should avoid busy streets and roads such as arterial streets with high levels of traffic speed and complex intersections that might increase children's exposure to motorized traffic.

1.2- __Permeanility and legibility__

A street system where all the streets are connected leads to a more integrated and sustainable network for pedestrians, children and cyclists around the school boundary. This street system maximizes the number of walkable/cycleable routes between destinations and it will limit the use of cul-de-sacs that provide no access. As a result, this principle will allow the system to evolve over time to meet local needs.

Orthogonal and curvilinear streets networks are probably the most effective in terms of permeability. Organic street networks have evolved since medieval times in a haphazard manner and though they are very different from the other two layouts they can still be highly connected.

Figure 4 - Urban layouts: Orthogonal, curve and organic layout (Lahart et al., 2014)

Legibility or wayfinding refers to how people find their routes to certain locations. For pedestrians, cyclists and especially children on their journeys to school this is of particular interest, as they are more likely to walk along a street if the route is clear. The street network should draw people to focal points and therefore the more orthogonal a street network is the more legible it will be.

To increase effectiveness, the streets around focal points should be assessed to find out whether pedestrian facilities are adequate enough or not and whether traffic calming measures are being implemented.

Figure 5 - Focal points, for example a primary school (Lahart et al., 2014)

1.3- <u>Gateways and transition zones</u>

Gateways and transition zones are used to demarcate a point of arrival from another location. They are very important as they give the first impression of the new environment. They also play a role in traffic calming as they inform the driver that the context is changing, and that for example they are entering a school zone.

Elements that provide enclosure, street furniture or changes to the carriageway will create an effective impression. Special attention to schools is necessary so that vehicle drivers entering the school zone can perceive changes in the streets, thus increasing their attention and degree of caution along the links.

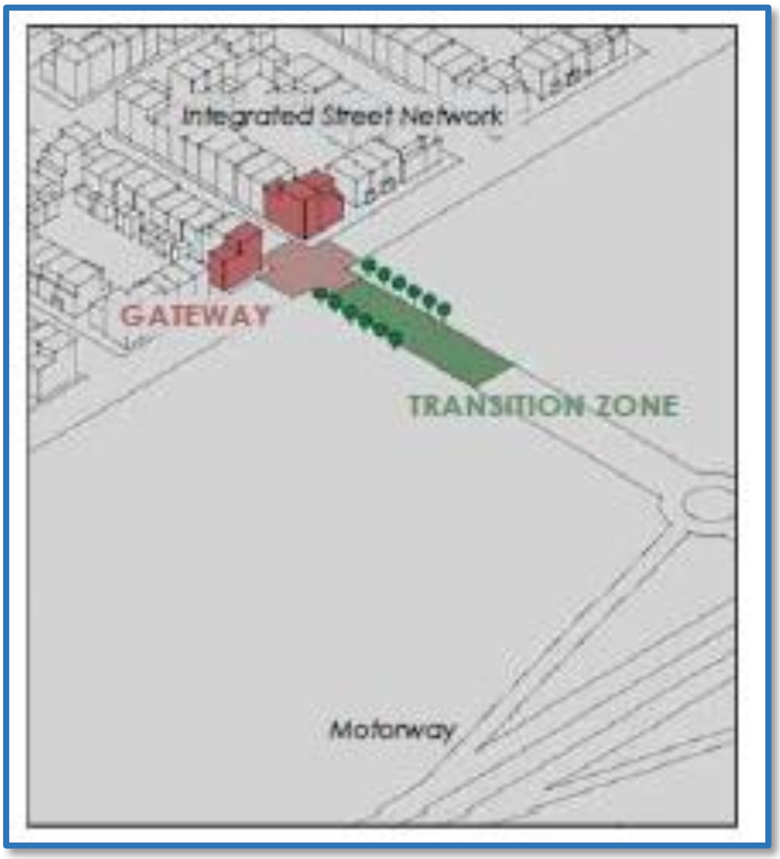


Figure 6 - Gateways and transition zones (Lahart et al., 2014)

1.4- Vehicle permeability

Vehicle drivers are more likely to drive along streets and roads with higher speed levels such as arterial streets when they drive longer distances. Permeable networks allow drivers to access individual properties more directly from those arterial streets and therefore they are more likely to comply with lower speed limits on local streets. These networks also provide a greater number of junctions making the drivers more cautious at these points.

This can also lead to a more equitable distribution of traffic volume throughout the network around primary schools, reducing traffic congestion, noise and air pollution. With these premises we obtain an increase in pedestrian, child and bicycle mobility as streets/junctions are more compact and easier to navigate.

The degree of permeability can be divided into:

- Dendritic: High degree of restrictions for all users
- Open network: Full permeability for all users
- 3 way Off-set: Network with several 3 way junctions
- Filtered permeability: Network that allows permeability just for a certain group of users.

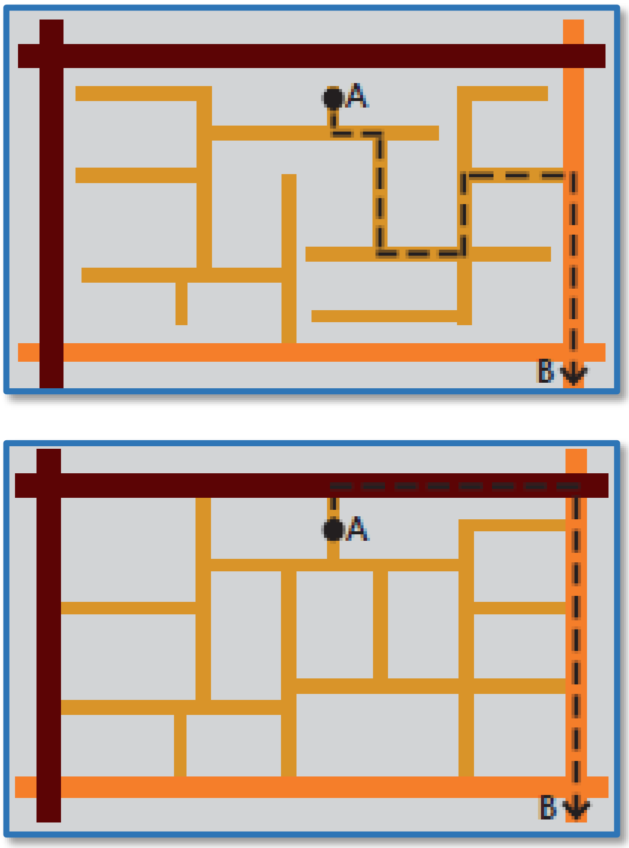


Figure 7 - Vehicle permeability (Lahart et al., 2014)

1.5- One-way streets

One-way streets have been used to reduce traffic volume and to filter permeability but they should be used cautiously as they might promote faster speeds, because drivers perceive less risk from oncoming traffic. They might be beneficial on narrow carriageways by providing additional space for pedestrians and cyclists.

School zone plans should assess the street network by including one-way streets and speed reducing measures in order to find potential links where drivers might drive at higher speeds.

1.6- Permeable network

One of the consequences of a permeable network is less car dependency and an increase in the use of sustainable modes of transport, this being the most balanced way of reducing traffic volume.

Slower vehicle speeds can lead to an increase in traffic capacity and more frequent minor junctions with lower vehicle movement are more attractive for pedestrians and cyclists to navigate.

Figure 8 - Permeable network (Lahart et al., 2014)

1.7- Public transport

Public transport is the key element for sustainable movement in a city but the street category must be taken into account. Bus services should be primarily addressed through arterial and link streets as they are the most direct routes between locations while transport services on local streets should be limited. The nature of these streets render this sort of service inefficient.

By looking at possible remote drop-off locations on a map, decision makers can identify the best places that will have the least impact on traffic, provide the safest and most direct routes for students, and allow the students to walk an appropriate distance to and from school and the bus.

1.8- <u>Inner and Outer streets</u>

It is, however, also recognized that a city has the need for streets and roads that provide a more efficient and fast displacement for larger volumes of vehicle traffic over longer distances, and therefore these streets are called relief roads or urban relief roads. Inner relief roads are generally used to address traffic within an urban area away from the city center, while urban relief roads are generally routed around urban areas and are often called outer relief roads.

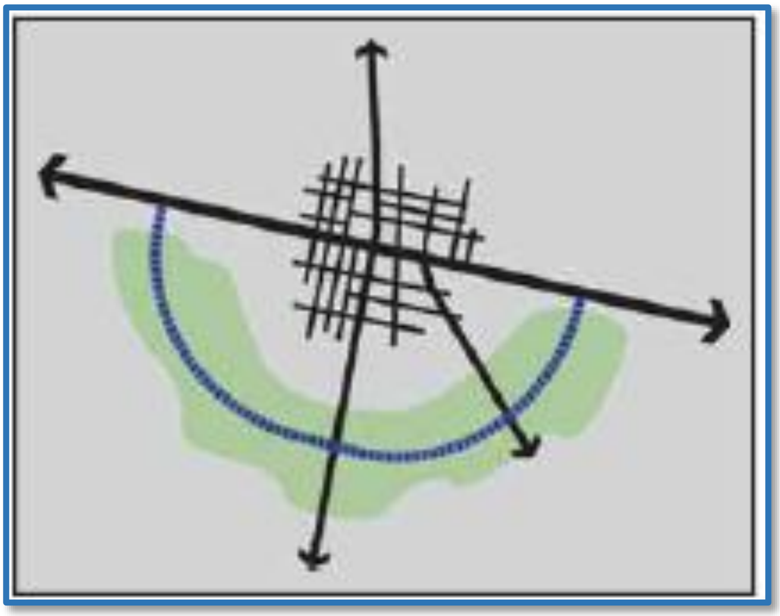


Figure 9 - Inner and Outer relief roads (Lahart et al., 2014)

2- STREETS AND ROADS CRITERIA

We will base this section mainly in *HB-100 – Streets and Roads Design (*Statens and Vegdirektoratet, 2014) but also on the two manuals utilized in the first section. A road or street system will be composed of links with different transport functions that require different configurations. Following this criteria, one can determine the degree of differentiation and separation for each kind of link and therefore transport functions can be prioritized.

Transport function can be determined by answering the following questions:

- Does the link have national/international importance?
- Is availability more important than efficient transportation?
- How does the link facilitate pedestrians, cyclists and public transport?
- Does the link have enough capacity for predictable traffic?

Solutions for pedestrians and cyclists along streets can be seen in the context of the main roads, intersections, exits and local road networks. In low density populated areas, it may be possible to provide a shoulder but this is not recommended when the route leads to schools. Cities and towns are planned to embrace pedestrian and bicycle traffic where they might share the same facility. To achieve an effective network, pedestrian and bicycle routes should be considered at planning levels.

The design of a road or street depends on environment, speed limits and traffic volumes, among other transport functions and modes of transport. Streets, roads and highways are planned and designed according to different principles. A very important and difficult task is to decide where the street begins and the road ends. Usually, in rural areas outside the city, roads are the primary solution while in urban or suburban centers the network is a mixture of streets and roads with different purposes. Roads are mainly designed to absolve higher amounts of traffic volume at higher speed levels, while streets are more focused on providing access to local streets and dwellings.

The main criteria for streets is a speed limit ranging from 30km/h to 50 km/h. Mixed traffic with a low speed limit at either 30 km/h or 40 km/h is relevant when:

- The street has many activities taking place on both sides
- Pedestrians, cyclists and neighborhood has priority

Sometimes, traffic separation of pedestrians and cyclists and motorized traffic is applicable at 50 km/h when the street's primary function is the transport of motorized vehicles and the street has an important status in the network hierarchy.

Speed reducing measures may be necessary in some cases to achieve low speed levels. Speed reducing measures are described in more detail in *Handbook V128 Speed reducing measures.*

In cities and towns, the objective is to define coherent network for each mode of transport:

- Pedestrian traffic
- Bicycle traffic
- Passenger traffic
- Transit traffic
- Commercial traffic

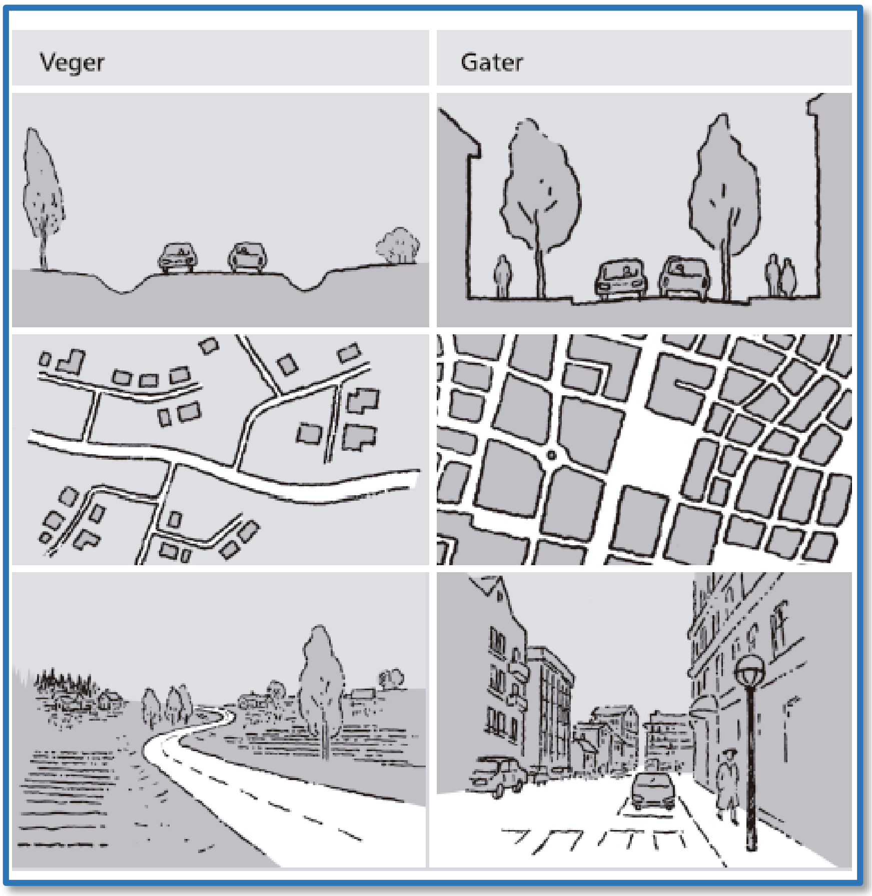


Figure 10 - Roads and Streets(Statens and Vegdirektoratet, 2014)

Sometimes, the street network will have overlapping modes of transport. How the individual road users are prioritized at each link together with the street's function will determine the correspondent design of the street cross section.

An appropriate street design response can successfully provide the needs of different users, improve enclosure and manage speed levels without resorting to extreme measures. These types of environments are called self-regulating systems. There is not a formal or standardized way in which this should be applied, but these premises can be considered:

- Use physical and psychological measures together
- High frequency and intensity of these measures result in lower operating speed

A study conducted in Dublin in 2011 *(Lahart et al., 2014)* demonstrated that "*a strong trend whereby as the frequency and strength of the psychological and physical design measures increased, the lower the operating speed and the greater the level of compliance with the posted speed limit*."

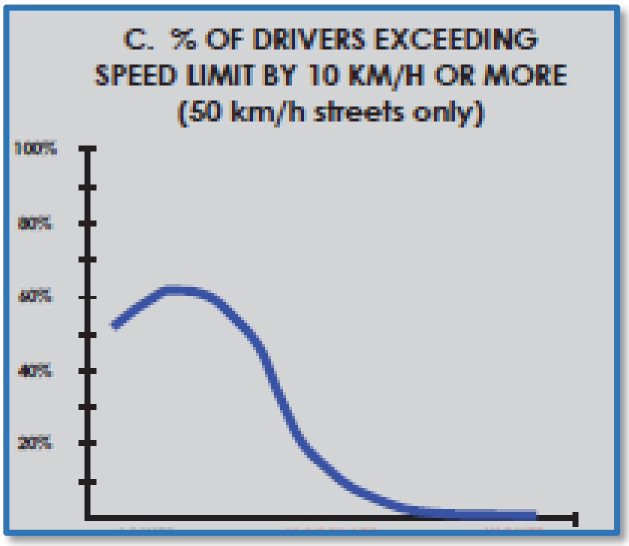


Figure 11 - Self-regulating systems (Lahart et al., 2014)

From a general point of view, a road or street can be divided into three main sections:

- The footpath where pedestrian walks
- Carriageway for vehicle traffic
- Lanes for parking/bike or loading.

2.1- Sidewalk

Sidewalks are the main solution for facilitating pedestrian movement and these should be situated on both sides of a street or road. In residential areas with local streets bearing lower traffic volume levels and with speed limits of 30 km/h, sidewalks could be placed on just one side, or the roadway might be shared.

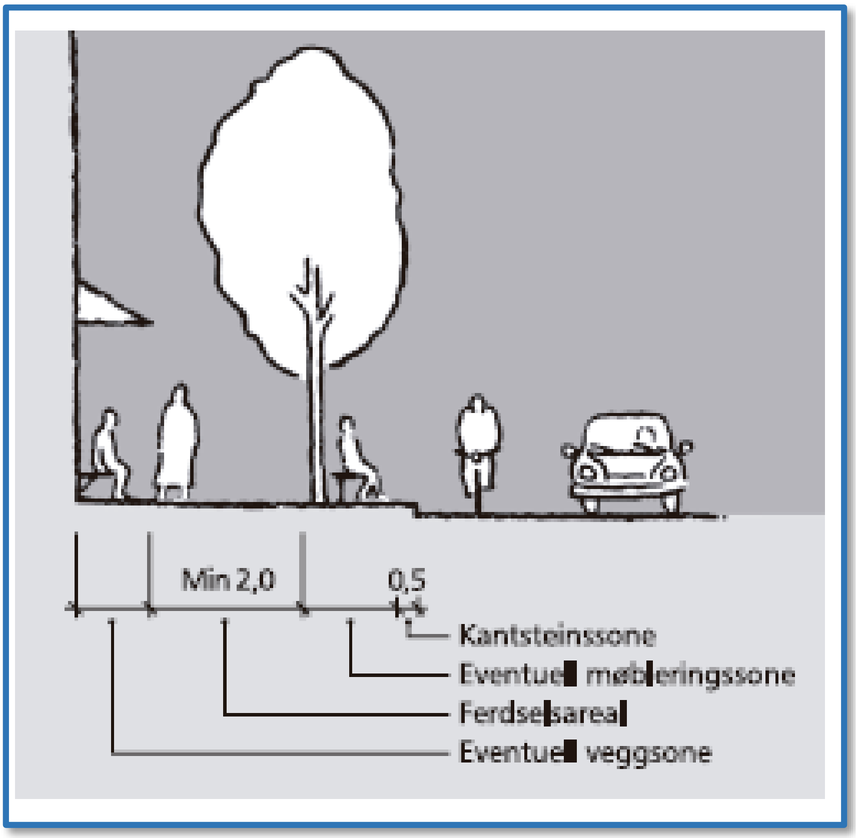


Figure 12 - Street cross section (Statens and Vegdirektoratet, 2014)

The minimum width for sidewalks is 2.5 m including curb zones to enable winter machinery to clear the footway. In streets or roads with much pedestrian activity, a width range of 4 m to 10 m provides enough room for a comfortable walk. If buffers are included, there should be enough space for winter machinery to clear the footway.

Trees and greenery can contribute to increasing the sense of enclosure while at the same time acting as traffic calming, noise reduction, and air pollution reduction measures. They can also highlight the importance of a route or a certain location.

Zone	Use	Recommendation
Verge	Zone against facade, f. Ex benches, stairs, access	News to build the shopping and stay streets and in residential streets with low 1st floor. Buyers and width requirements defined through municipal planning
Footway or sidewalk	Pedestrian traffic	All sidewalks to have traffic zone of minimum width 2 m
Furniture zone or strip	Buffer against traffic. Space for stays, signs, trees or other plantings, benches, bicycles etc.	May be instituted in all streets. Buyers clarified through municipal planning
Curb zone	Zone free of obstacles	All sidewalks should have curb zone. Curb zone should be at least 0.5 m. Bus bays should be at least 0.7 m

Table 2 - Street zones (Statens and Vegdirektoratet, 2014)

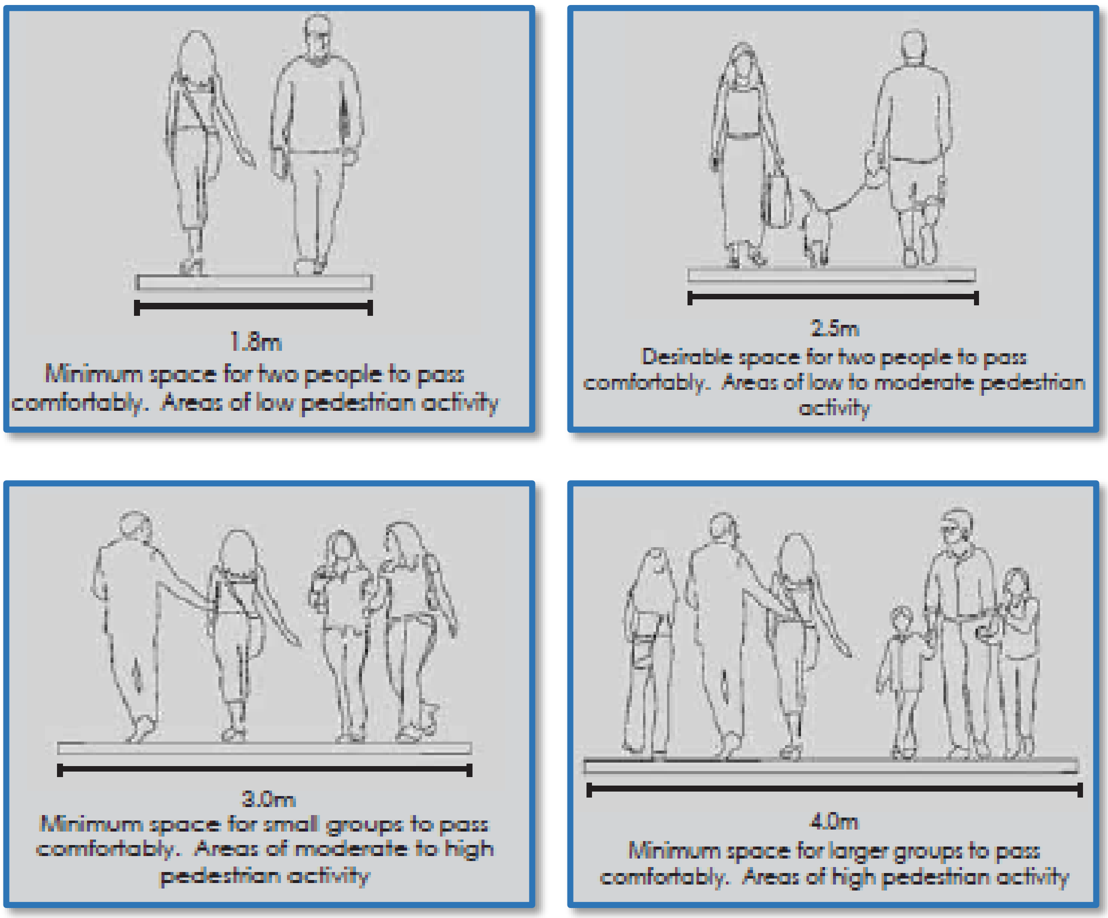


Figure 13 - Sidewalk width requirements (Statens and Vegdirektoratet, 2014)

2.2- Curb zone

Curbs originally had a drainage function but recently have come to define the transition between the domain of the pedestrian and the roadway. They serve to establish the degree of segregation or integration in a street network.

Curbs are mainly used to define areas for motorized traffic. For aesthetic reasons, it is recommended that curb lines are designed with blocks and that they have a constant radius at intersections.

Lower curbs ranging from 4 cm to 10 cm are suitable for improved accessibility for both pedestrians and cyclists but the ADT should be < 4.000 and the speed limit between 30 km/h and 40 km/h.

As a general rule, curb clearance width should be 0.25 m.

2.3- Carriageway

Carriage width is highly correlated with speed levels. This means that streets and roads should only have the necessary lanes and that they should be of the corresponding width, avoiding very wide lanes that might increase the feeling of security of drivers, thus encouraging them to drive faster.

Roadway cross section may consist of:

- lane
- cycle lanes
- parking lanes
- bus lanes

Explanations of abbreviations in cross section drawings are as follows:

- Kk = curb clearance
- Sf = bicycle lanes
- KJF = lane
- Kof = bus lanes

2.3.1- One lane

The following figure shows when streets can be built with one lane depending on speed limit and ADT traffic volume. Widths are expressed in centimeters.

Bruksområde	Tverrprofil
Fartsgrense 30 km/t og ÅDT < 300 Det bør være møte eller passeringsmulighet for hver 100 meter	Kk 0,25 · Kjf 3,5 · Kk 0,25

Figure 14 - One lane (Statens and Vegdirektoratet, 2014)

2.3.2- <u>Two lanes</u>

The following figure shows when streets can be built with one lane depending on speed limit and ADT traffic volume. Widths are expressed in centimeters.

Tabell B.3: Gate med 2 kjørefelt (mål i m)

Bruksområde	Tverrprofil
Fartsgrense 30 - 40 km/t ÅDT 0 - 4000 og ÅDT tunge < 100	Kk 0,25 · Kjf 2,75 · Kjf 2,75 · Kk 0,25
Fartsgrense 30 - 40 km/t ÅDT 0 - 4000 og ÅDT tunge > 100 eller ÅDT 4000 - 15000 **Fartsgrense 50 km/t** ÅDT 0 - 8000	Kk 0,25 · Kjf 3,0 · Kjf 3,0 · Kk 0,25
Fartsgrense 50 km/t ÅDT 8000 - 15000	Kk 0,25 · Kjf 3,25 · Kjf 3,25 · Kk 0,25

Figure 15 - Two lanes (Statens and Vegdirektoratet, 2014)

In streets with 50 km / h, AADT 8,000 - 15,000 and little heavy traffic the lane width could be reduced to 3 m. Cycle lanes, bus lanes, shared use lanes, bus stops, goods delivery lanes or parking lanes can also be presented. The following sections shows the requirements.

2.4- <u>Bike lane</u>

All streets that are included in the main bicycle planning route should have bicycle lane present if:

- ADT> 4000 or
- Speed limit of 50 km / h

Sidewalks and pedestrian areas should not be included as links in the main network for bicycles. Main routes for bicycles should not be in the same lane as the carriageway. The following figure shows the requirements for cycle lane width. They will be built at the same level as the other lanes reserved for motorized traffic and they will normally be on both sides. However it might be possible to have one-side cycle lanes in some cases.

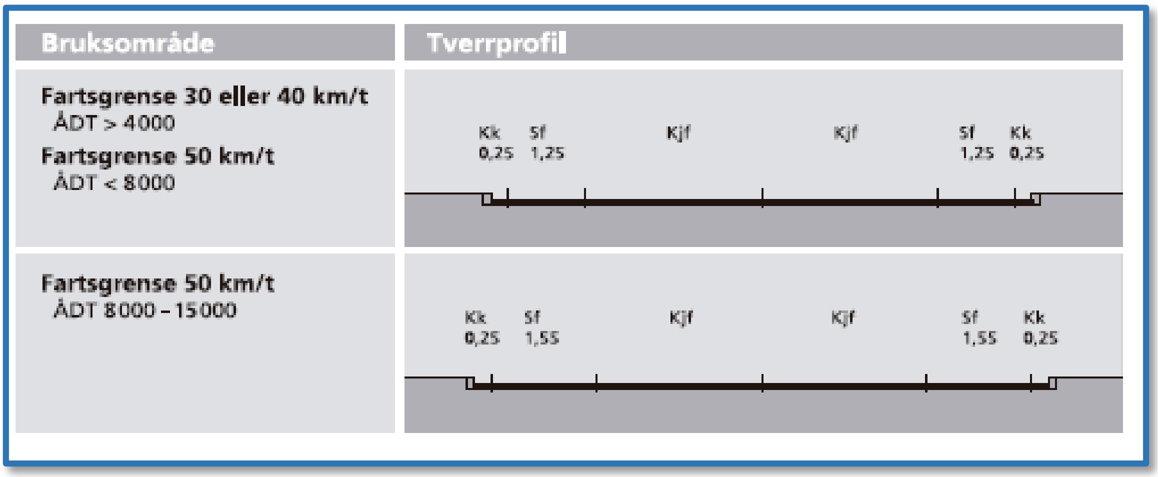


Figure 16 - Bike lane (Statens and Vegdirektoratet, 2014)

The following figure shows an overview of the integration and segregation of cycle traffic within the carriageway based on vehicle speeds and traffic volumes:

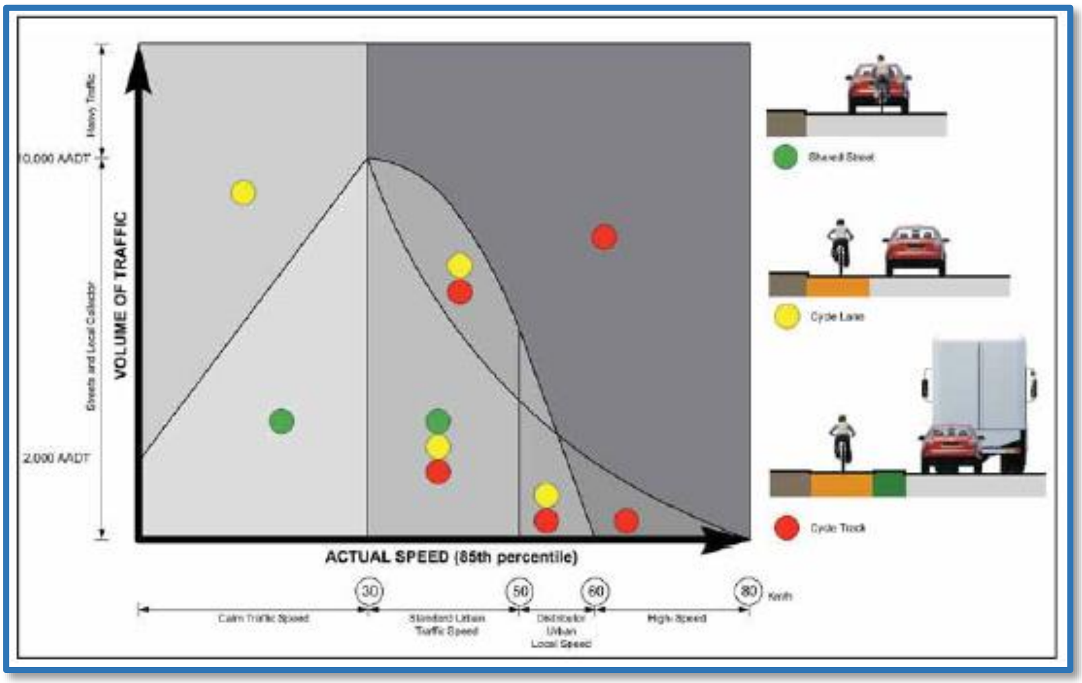


Figure 17 - Integration or segregation of cycle traffic(Lahart et al., 2014)

2.5- ***<u>Parking</u>***

This refers to spaces that allow a direct connection to the carriageway by parked vehicles. It helps to calm traffic by narrowing the lane width and also increasing activities on streets because people can stop to visit commercial areas. In the same way, they act as a buffer between pedestrians and motorized traffic resulting in a more comfortable and safer environment.

As a general rule, on-street parking alone can be implemented for residential densities up to 35-40 dwellings per ha, but once a level of 40-50 dwellings per ha is reached it should be substituted by off-street parking with parking lanes. More than 50 dwellings per ha will require special off-street areas such as basement car parks. Parking bays should be parallel on arterial and link streets while other geometric designs can be implemented in lower category streets.

Combined cycle lanes and parking lanes are not recommended. However, if this combination is used the following criteria should be assumed:

- speed limit is 30 or 40 km / h and ADT <8000
- cycle lane should be extended by 0.25 m
- A safety zone of at least 0.5 m should be established between the parking lane and cycle lane

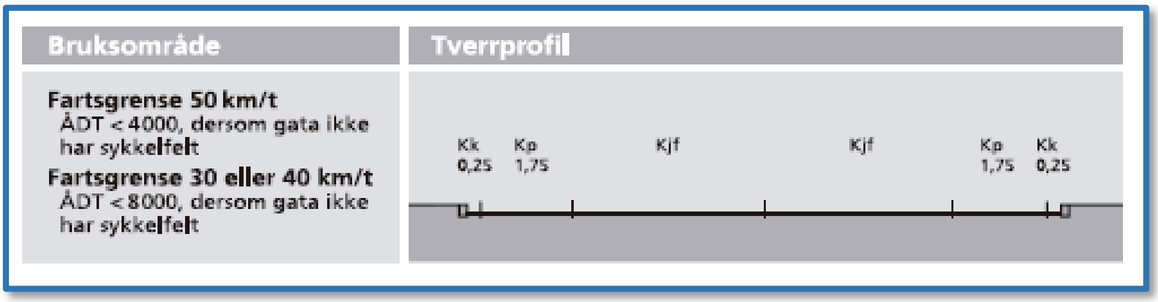


Figure 18 - Parking lane(Statens and Vegdirektoratet, 2014)

2.6- Lighting

Lighting should be designed to ensure that both the carriageway and the pedestrian/cycling facilities are correctly illuminated. Good lighting provides a safer environment by ensuring intervisibility among all users, while poor lighting conditions might make it difficult for vehicle drivers to identify potential hazards. When lighting requirements are not met the street might be perceived as an unsafe environment, thus discouraging people from walking or cycling.

Figure 19 - Lighting conditions (Lahart et al., 2014)

3- PEDESTRIAN CROSSINGS CRITERIA

We will base this section mainly on *HB – 127 Pedestrian Crossing criteria (Vegdirektoratet and Statens, 2014),* which is intended to make suggestions for each type of street according to its speed limit, those that should have pedestrian crossings and which type of design should be used. In addition, we will consider the two manuals presented in the first section.

It is important to see the street network as a whole when it comes to assessing pedestrian crossings. One should consider road type, function, standards and speed limit within the context of a larger geographic area, before making a decision and deciding where to install a new pedestrian crossing.

It is assumed that cities and towns have a continuous vehicle traffic flow, but how this is prioritized against pedestrians, together with the street function, is decisive in shaping the streetscape. However, it is important that street networks ensure good and safe walkability at peak hours, especially around features such as residential areas, schools, workplaces, and central urban areas. The design should contribute to the perception of streets as a safe and attractive place to walk.

Pedestrians are especially sensitive to vertical walking and they would rather cross the street horizontally than going under/over special facilities traversing the street or road. Although some of these facilities may be installed on certain streets, they should be attractive from a Universal Design point of view.

Pedestrian crossings are one of the most important factors in a street network as it is at these points where pedestrians cross the street and therefore a crucial interaction between road users occurs there. Well-designed facilities are essential to providing a balanced movement along the streets, and they have a profound impact on pedestrian walkability/cycle mobility.

The location and frequency of crossings should be assessed via spatial analysis and supporting plans. Pedestrians and cyclist movements should be given priority at intersections in order to reduce waiting times and crossing distances.

3.1- Streets with speed limit of 30 km/h

In principle, it is not mandatory to install pedestrian crossings in this type of street. Where there are pedestrian crossings, however, the actual speed should be less than 35 km/h. If it is not the case, speed-reducing measures should be considered.

Pure residential areas with 30 km/h should not have pedestrian crossings. This type of street is often designed to ensure low speed and is often intersected at many locations, with pedestrians and cyclists frequently using the whole section. Speed-reducing measures should be installed to ensure proper speed levels.

Only roads with considerable vehicle traffic volume or pedestrian volume should have facilities that segregate traffic flows (ADT > 8.000 or 40 pedestrian crossings at peak hour).

3.2- Streets with speed limit of 40 km/h

These streets are typically collector roads in residential and downtown areas

In general, pedestrian crossings should be considered if there are more than 20 crossings at peak hour or ADT > 2.000. Speed level should be less than 40 km/h. If it is not the case, speed-reducing measures should be considered.

The type of traffic flow, ADT and road function should be assessed in order to determine whether to install 30 km/h or 40 km/h in residential and downtown areas.

3.3- Streets with speed limit of 50 km/h

In general, pedestrian crossings should be considered if there are more than 20 crossings at peak hour or ADT > 2.000. Speed level should be less than 45 km/h. If it is not the case, speed-reducing measures should be considered.

It is difficult to secure these types of street as they often carry road congestion, especially for emergency vehicles and buses. Therefore, 50-sections become really important to provide accessibility in a more general road network, and it would be undesirable to lose such a differentiation. Installing speed-reducing measures might lead to permeability into streets that are less suitable for ensuring traffic flow (streets with 30km/h and 40/h speed limit).

Pedestrian phasing should be installed when ADT > 5.000. Installing additional measures to prioritize the maneuverability of pedestrians should be considered when ADT > 8.000.

Also, it is important to control the continuous variation of speed limit as it might be difficult to perceive danger from a driver perspective. Speed limit of 30 or 40 on 50-routes should be only installed at certain locations such as schools.

3.4- __Pedestrian phasing__

In the table of pedestrian crossings criteria is indicated when the signal controlled pedestrian crossing on the stretch may be applicable. The required number of crossings must always be met. ADT must be> 5000 when the speed limit is 30, 40 or 50 km / h. At a speed limit of 60 km / h, signal controlled crossings are relevant in AADT of 2000. Operating Field ensured by speed-reducing measures / and or advance warning with attention increasing action if the speed level is 65 km / h or more.

3.5- __Lighting__

To reduce the risk of accidents in darkness, pedestrian crossings should be illuminated. A large proportion of crossing accidents occur in the dark. One reason for this is that the usual road / street lighting is not good enough. Improvement of lighting is therefore an important measure for securing points where people cross the street.

Construction of good road lighting on unlit roads reduces the risk of accidents for all traffic groups. In effect, the handbook states that fatalities in the dark is reduced by an average of 50% and the number of people injured in the dark in total by 32% when bad road lighting is improved.

3.6- __Median/refugee islands__

In general, pedestrian crossings should not be built over roads with more than one lane in each direction. As an exception, it is permitted to build pedestrian crossings on roads with more than one lane in each direction if the speed level is not higher than 40 km/h, along with refuge islands or medians. In such cases, it is mandatory to implement speed reducing measures or measures to increase driver awareness of pedestrians.

3.7- Speed Reducing Measures

Streets and roads should have a driving speed which is safe and environmentally prudent. However, this is often not the case. To provide further guidance on what is considered the maximum acceptable speed, a system of speed limits is introduced.

The general speed limit of 50 kmh is for built-up areas and 80 km/h for rural areas. It is also permitted to apply special speed limits (both lower and higher than general) depending on the conditions of the road and the surroundings. Speed reducing measures can be divided into physical measures and other measures.

The purpose of speed damping and speed reducing measures is primarily to improve traffic safety. There is a clear correlation between speed and the number of accidents, not to mention accident severity. The following figure shows the relationship between the driving speed of the motor vehicle and mortality when colliding with pedestrians.

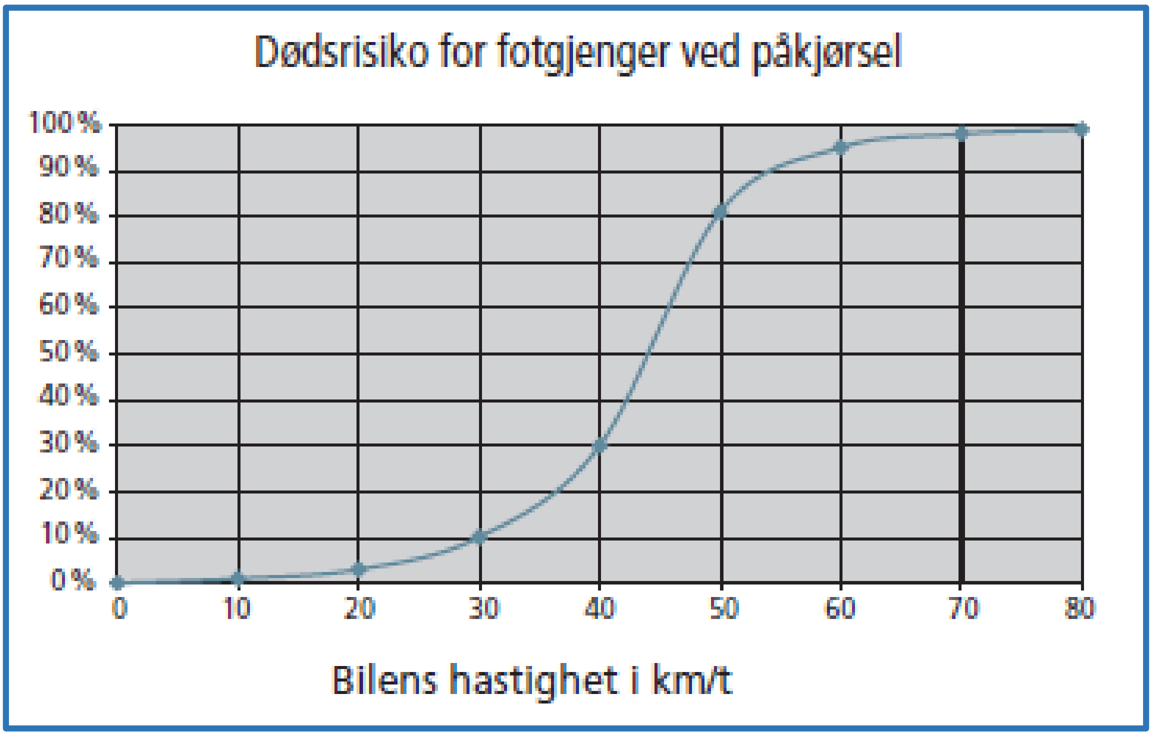


Figure 20 - Relation speed and mortality risk (Vegdirektoratet and Statens, 2014)

3.8- Pedestrian crossing facilities

The following tables show the criteria recommended for each street or road according to their speed limit and ADT:

ADT	Type of Road	Pedestrian Volume	Recommendation	Additional Measures
Speed limit is 30 km / h (Requirement speed level at maximum 35 km / h)				
0 – 4.000	Roads often without sidewalk and disperse crossing. Example: Residential streets or downtown streets.	0 – 40 >30 with special needs	Not new pedestrian crossings. Consider pedestrian crossings at key walking routes.	Sufficient number of bumps so that the speed level is at <35 km / h. In residential streets 30 zone, existing crossings removed (supplementing bumps considered). Applicable special cases in the city streets. Raised pedestrian crossing or elevated cross.
4.000 – 8.000	Roads often with sidewalk but some disperse crossing. Downtown streets.	0 – 30 >30 with special needs	Not new pedestrian crossings. Consider pedestrian crossings at key walking routes.	Sufficient number of bumps. Applicable special cases in the city streets. Raised pedestrian crossing or elevated cross.
> 8.000	Roads with sidewalks and much crossing at intersection. Downtown streets.	0 – 20 >30 with special needs	Not new pedestrian crossings. Consider pedestrian crossings at key walking routes.	Sufficient number of bumps. Applicable special cases in the city streets. Raised pedestrian crossing or raised intersections, traffic island.

Table 3 - Pedestrian Criteria 30 km/h (Vegdirektoratet and Statens, 2014)

ADT	Type of Road	Pedestrian Volume	Recommendation	Additional Measures
Speed limit 40 and 50 km / h (Requirement speed level respectively maximum 40 km / h and 45 km / h)				
0 – 2.000	Roads often with sidewalk but some disperse crossing at many places	0 – 30 >30 with special needs	Not new pedestrian crossings. Consider pedestrian crossings at key walking routes.	Raised pedestrian crossing / traffic island / Narrowing / Travel Pillows / Speed to 30 km / h and elevated pedestrian crossings
2.000 – 8.000	Roads often with sidewalk. Crossing is somehow disperse and concentrated at some locations.	0 – 20 >20 with special needs	Not new pedestrian crossings. Consider pedestrian crossings at key walking routes.	Raised pedestrian crossing / traffic island / Narrowing / Travel Pillows / Speed to 30 km / h and elevated pedestrian crossings Signal Regulation (ADT should be 5000)
> 8.000	Roads with sidewalk and crossing concentrated at adapted locations.	0 – 10 >10 with special needs	Not new pedestrian crossings. Consider pedestrian crossings at key walking routes.	Raised pedestrian crossing / traffic island / Narrowing / Travel Pillows / Speed to 30 km / h and elevated pedestrian crossings signaling

Table 4 - Pedestrian crossings at 40-50 km/h (Vegdirektoratet and Statens, 2014)

ADT	Type of Road	Pedestrian Volume	Recommendation	Additional Measures
Speed limit 60 km / h - not construction contents of pedestrian crossings				
0 – 2.000	Roads with moderate activity of pedestrian and bicyclists. Traffic segregation with proper facilities.	0 – 20 >20 with special needs	Not new pedestrian crossings. May consider a pedestrian crossing but then the speed level down to <45 km / h.	Speed limit (50/40/30) and speed-reducing measures. At roundabouts where the speed level is <45 km / h can be installed crossings.
2.000 – 8.000	Roads with moderate activity of pedestrian and bicyclists. Traffic segregation with proper facilities.	0 – 20 >20 with special needs	Not new pedestrian crossings. Signal control 4) and the speed level <65 km / h.	If not signalreg., Must speed limit parted down (50/40/30) and speed-reducing measures are added or grade separated crossing built. At roundabouts where the speed level is <45 km / h can be installed crossings.
> 8.000	Roads with moderate activity of pedestrian and bicyclists. Traffic segregation with proper facilities.	-	Not new pedestrian crossings. Signal control 4) and the speed level <65 km / h. Plan Signs should be considered.	If not signalreg., Must speed limit parted down (50/40/30) and speed-reducing measures are added or grade separated crossing built. At roundabouts where the speed level is <45 km / h can be installed crossings.

Table 5 - edestrian crossings at 60 km/h (Vegdirektoratet and Statens, 2014)

CHAPTER III:

Building a Network for Pedestrians

III) BUILDING A NETWORK FOR PEDESTRIANS

1- CREATION OF THE NETWORK DATASET

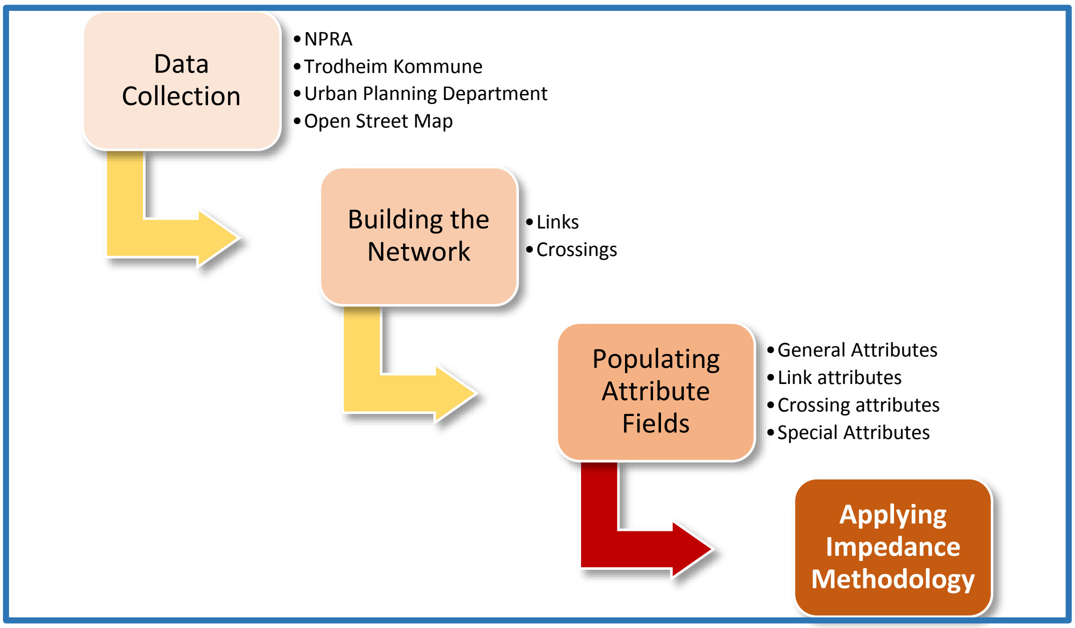


Figure 21- Building Network Scheme

One of the most important processes when planning a Safe Routes to School Program is to identify the safest routes for children. School route maps can help to inform students of the safest and most convenient routes to school and to identify areas where there might be some hazardous events and that should be reassessed in order to implement safety measures.*(Brown et al., 2015)*

Most street networks only refer to the center line of a street because they are vehicle orientated, but a few indicate where pedestrians can walk and cross the street around the city. The main purpose of this section is to present a method for building such a pedestrian network.

This network will mainly be composed of:

- Polylines that represent where pedestrian can walk along a street.
- Polylines that represent where pedestrians can cross the street.
- Polylines that represent open field paths and shared use streets where pedestrian can walk.

Our network will perform an analysis based upon two main criteria; walking time or distance, and insecurity time. The first variable will be related to short routes while the second variable will be related to routes with the lowest feeling of insecurity.

We will now present the methodology for building a network on which school route maps will be based. These routes will indicate where pedestrians experience the lowest feeling of insecurity, regardless of the traffic safety measures implemented. Nevertheless, the factors of traffic safety and insecurity may be interrelated as streets with the lowest feeling of insecurity will often have more traffic safety measures implemented along their routes.

2- BASED DATASETS

Before commencing this section, the reader is advised that many technical expressions related to GIS will be used to describe the complex analyses that have been performed.

On this basis, non GIS-familiar readers may have difficulties in properly following and understanding the following subsections.

2.1- Basic Concepts

2.1.1- What is a spatial reference?

This can be defined as follows:

"Geographical data for any particular area is stored in separate layers. For example, roads are stored in one layer, parcels of land in another, and buildings in a third. To enable the data in each layer to integrate when displayed and queried, each layer must reference locations on the Earth's surface in the same manner. Coordinate systems provide this framework and they also provide the framework that enables data in different regions to be referenced in different ways. Each layer in the geodatabase has a coordinate system that defines how its locations are geo-referenced" (ESRI, 2017)

Therefore, it is of paramount importance that all of the data is utilized according to a common spatial reference, thus making it easier to work with this data within the same framework. Data from different sources will be used and with ArcGIS it is possible to convert material from different spatial references to the same one.

2.1.2- What is a dataset?

A dataset can be defined as follows:

"A feature dataset is a collection of related feature classes that share a common coordinate system. Feature datasets are used to spatially or thematically integrate related feature classes. Their primary purpose is for organizing related feature classes into a common dataset for building a topology, a network dataset, a terrain dataset, or a geometric network" (ESRI, 2017)

Datasets will be used as the main source of information to build our network and it will contain all the data needed to perform our future analysis.

2.1.3- What is a network?

A geometric network can be defined as follows:

"Geometric networks offer a way to model common networks and infrastructures found in the real world. Water distribution, electrical lines, gas pipelines, telephone services, and water flow in a stream are all examples of resource flows that can be modelled and analyzed using a geometric network" (ESRI, 2017)

We can benefit from these networks when performing various analyses. The following are some examples:

- Shortest path between two points.
- Shortest path from a facility to an area or region.
- Determine flow directions.

A geometric network is built within a feature dataset in the geodatabase. The feature classes in the feature dataset are used as the data sources for network polylines.

2.2- Dataset collection

Data from different sources in different formats (cad, raster and vector) and different projections / coordinate systems have been used for the Singsaker case study.

Therefore, an important data preparation process has been carried out in order to standardize formats and to define the most appropriate coordinate system (WGS 1984 UTM 32N) for all datasets to be used in further analysis.

Many different sources have been employed for the case study:

2.2.1- The Norwegian Public Road Administration (NPRA)

Thanks to Jensen Jan Kristian *(Senioringeniør vegdirektoratet/NVDB og Geodata at Statens vegvesen/vegdirektoratet),* I was introduced to the National Road Data Bank.

The National Road Data Bank (NVDB) contains the country's road networks and a large quantity of traffic data related to the road network. The NPRA aims to make information freely available and encourages the public to use the data base creatively.

A map for each data set is available at the NDVB (2017), a public online service provided by the Norwegian Public Administration of Roads.

The following datasets have been used:

- Fartsdemper: Dataset that includes physical measures to reduce speed.
- Fartsgrense: Dataset including speed limits in all the street network.
- Fortau: Dataset that includes information regarding sidewalks.
- Funksjonell: Dataset that classifies the street network according to its function.
- Gangfelt: Dataset that includes all the pedestrian crossings within the street network as well as information about physical features.
- Skiltplate: Dataset including all signposts catalogued as well as their location within the street network.
- Traffikkmenge: Dataset that includes information about traffic volume for the whole street network.
- Trafikkulykke: Dataset that includes accident data.
- Ulykkesinvolvert: Dataset that includes accident data per unit involved.
- Ulykespunkt: Dataset that includes blackspot data.
- Vegreferanse: Dataset that includes the center line for each street or road.
- Vegskulder: Dataset that includes information about presence or otherwise of shoulder.

2.2.2- Department of Architecture and Planning

With the purpose of obtaining vectorial data regarding the city of Trondheim, Yngve Karl Frøyen, head of the department, was contacted. He provided me with a network that represents all the walkable and cycleable paths (gangnett and syklkenett), which was of great assistance when building the new pedestrian network. He also provided me with vectorial datasets regarding buildings, land use, administrative boundaries and road networks.

2.2.3- Open Street Map (OSM)

Open Street Maps (OSM) were used to complete the network for pedestrians as they often include missing paths that are not indicated in official datasets. In particular, two main datasets were downloaded in convenient projection system: Geobrick and Mapzen.

2.2.4- Trondheim Kommune

Trondheim Kommune has collaborated with this project on many occasions. First, they were requested to provide information regarding school traffic safety and consequently I was provided with many documents for the purpose of my thesis. Thanks to Thomas Jonsson (NTNU, Civil and Transport Engineering Department) I was put in contact with Erlend Oskar Wold, an employee at the Urban Office, who collaborated by sharing a report from the period 2012 – 2016 regarding school traffic safety issues. In this document, a map was included with all of the locations where children were facing difficulties and also where parents had expressed concerns regarding their children's route to school. (Kommune, 2012) A copy of this map report can be found in Singsaker *Map Appendix 3K – Singsaker School Report*.

Another employee at the Urban Office, Relling Svein Åge, provided a WMS service with an urban map of the city of Trondheim which was used as the template for all of the maps. He also gave me advice on how to build a network for pedestrians.

And finally, Wenche Stinessen, also from the Urban Office, was requested to provide a dataset including children's routes to school. As this type of data is considered sensitive, it was not possible to obtain the individual route for a child that might identify them. However, a map showing all the routes drawn on a map was provided where one can gain an overall picture regarding which streets are most walked by children. (Kommune, 2013) A copy of this map can be found in *Map Set Appendix 3J – Singsaker Children's Routes*

3- MAIN ATRIBUTTES OF THE NETWORK DATASET

The attributes in our network will be divided into:

- General attributes: General information for both links and crossings.
- Link attributes: Attributes that are characteristics of streets rather than crossings.
- Crossing attributes: Attributes that are characteristic of crossing rather than streets.

Before considering each attribute, let us define some basic vocabulary.

3.1- Basic concepts

3.1.1- What is an attribute?

Our network will be populated with several attributes regarding the transport infrastructure and thus they have to be defined properly.

In ArcGIS Online help this is defined as follows:

"Network attributes are properties of the network elements that control traversability over the network. Examples of attributes include the time taken to travel a given length of road, which streets are restricted for which vehicles, the speeds along a given road, and which streets are one-way.

Network attributes have five basic properties: name, usage type, units, data type, and use by default" (ESRI, 2017).

What is a cost attribute?

As mentioned before, our analysis will be based on two basic cost attributes or impedances: walking time or distance, and insecurity time. Both are expressed in seconds but with a very different meaning which will be explained in following sections.

As we can find in ArcGIS Online Help:

"Certain attributes are used to measure and model impedances, such as travel time (transit time on a street) or demand (the volume of garbage picked up on a street). These attributes are apportionable along a link; that is, they are divided proportionately along the length of a link.

For example, if travel time is modelled as a cost attribute, traversing half a link will take half the time as does traversing the whole link: if the travel time to traverse the link is 3 minutes, it takes 1.5 minutes to traverse half the edge. If one is looking for a 1.5-minute route along this link, the route feature is created from the first half of the link feature.

Network analysis often involves the minimization of a cost (also known as impedance) during the calculation of a path (also known as finding the best route). Common examples include finding the fastest route (minimizing travel time) or the shortest route (minimizing distance). Travel time (drive time, pedestrian time) and distance (meters) are also cost attributes of the network dataset." (ESRI, 2017):

We are now going to explain the main attributes that our network will have and that will be used to determine the insecurity-cost and the length-cost along a certain route.

3.2- General Attributes

Here we will describe the general attributes that the network must have in order to work properly:

- Vegident: The identification related to Vegreferense dataset, so that it is possible to identify links and crossings with its Vegreferense center line.
- Hierarchy: The street category within the transport infrastructure according to its transport function:
  - Arterial street: Multiple lane traffic facilities that carry large volumes of traffic usually at high speeds and connecting different centers/nodes or towns.
  - Collector street: These streets provide movement through the city by connecting neighborhoods and giving access to highways or major roads.
  - Local street: The shortest and the narrowest streets giving access to residential areas, schools and parks with low traffic volume and often very low speed limits.
  - Residential street: A special category of local streets that give access to private areas.
  - Shared use street: Typically unpaved streets in private areas.

  - Paths: Typically go through open field and where vehicle traffic is not allowed.
- Name: The name of the street.
- One way: Whether it is possible to drive in both directions or not.
- Length: Total length of the segment in meters.
- Walk time: Total time spent in minutes in walking a certain segment.
- Crossing: Value = 0 if it is a link (street) or Value = 1 if it is a crosswalk.

3.3- Link attributes

The following attributes are typically for link or streets where pedestrian walk along parallel to the direction of the motorized traffic:

- Signalization: Signposts along the link indicating pedestrian walking or speed limit signals.
- Sidewalk: Type of sidewalk for each link, and width.
- Shoulder: Type of shoulder for each link, and width.
- Buffer: Existence or not of a buffer space on a link, and width.
- Bike lane: A lane reserved for bikes parallel to the link.
- Parking: Reserved space for car parking (either on-street parking or parking lane).
- Speed limit: Speed limit of the segment section parallel to the link.
- AADT: Total daily traffic volume for a section parallel to the link.
- AADT Heavy: Total daily heavy traffic volume for a section parallel to the link.
- Lighting: Presence or not of lights along the link.

3.4- Crossing attributes

The following attributes are typical for links or streets crossing perpendicular to the direction of the motorized traffic:

- Cross sign: Presence or not of signpost indicating a pedestrian crossing.
- Signalization: Speed limit signals or children signals nearby a pedestrian crossing.
- Marks: Painted marks indicating where pedestrian can cross the street.
- Raised: Whether the pedestrian crossing is raised or not.

- Traffic regulated: Whether the pedestrian crossing is regulated by traffic lights or not.
- Speed measures: Whether there are speed measures nearby the pedestrian crossing or not.
- Refugee/Median: Whether the pedestrian crossing has a refugee or median facility for large crossings.
- Cross level: Whether the pedestrian crossing it is a different level than the street or road to be crossed.
- Lighting: Whether the pedestrian crossing is illuminated or not.

3.5- Special attributes

This attributes are the result of applying the formulas presented in *Chapter IV: Feeling of Insecurity Impedance Methodology*. These attributes are used in network analysis:

- Link Impedance: The result of calculating the impedance for each polyline classified as a link according to the methodology presented. It is expressed in seconds and represents “feeling of insecurity in time while walking along a link”.
- Cross Impedance: The result of calculating the impedance for each polyline classified as a crossing according to the methodology presented. This is expressed in seconds and represents “feeling of insecurity in time while crossing a street”.

4- BUILDING THE SCHOOL NETWORK

As previously explained, there is not yet a complete network dataset for pedestrian walkable paths that simultaneously includes information about both links and crossings. Therefore, our first great challenge is to find a way to construct a suitable network that includes all the sidewalks and all the possible crossings (existent or not) as well as those paths separated from road traffic.

We basically divide our network in two type of polylines:

- Links: A polyline that represents a path where a pedestrian can walk.
- Crossings: A polyline that represents a place where a pedestrian can cross a street.

It will be also be necessary to add information about parking lanes, cycle lanes, buffer spaces and driveways as well as lighting and other conditions. For this, it might be necessary to conduct walkabouts within the school boundary in order to add the data that is not yet contained in the official datasets.

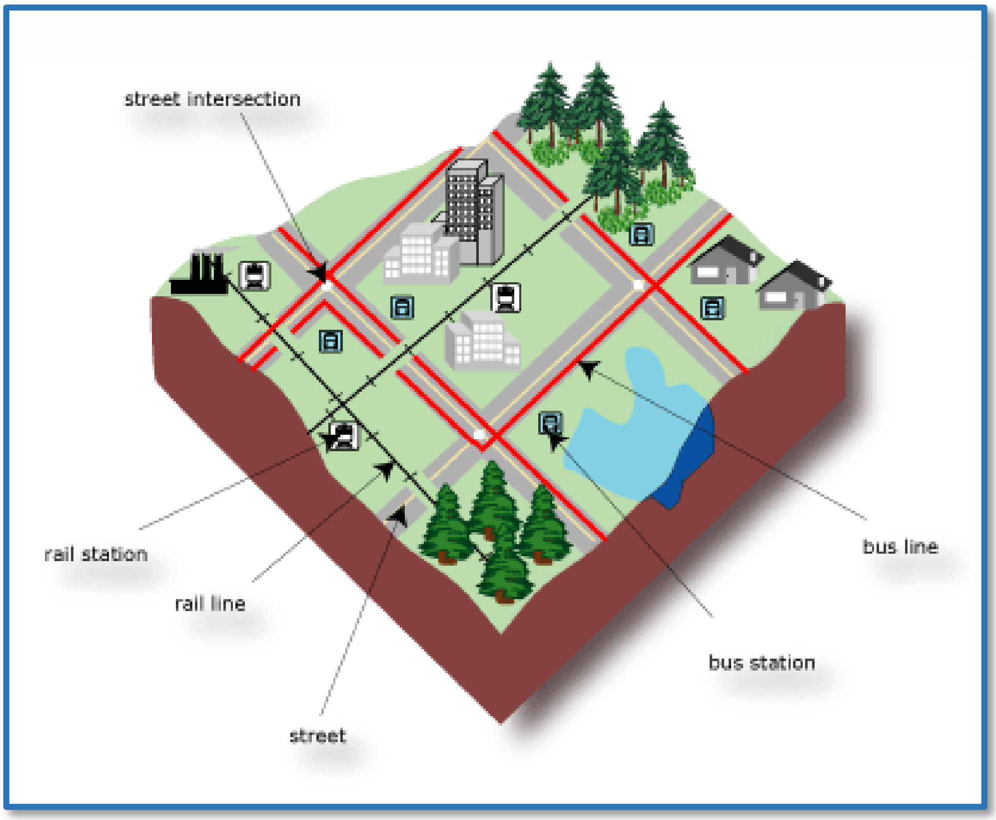


Figure 22 - Typical network dataset (ESRI, 2017)

4.1- Creating Links and crossing from the center line of a street

We have chosen to use the network "vegreferense" from the NRPA as our main network base map. Using the center line of each road, we have used the tool "copy parallel" in arcGIS to both sides, resulting in polylines that represent paths for pedestrians on both sides of a street or road. Crossing polylines have been manually added afterwards. The following figure shows a simple example:

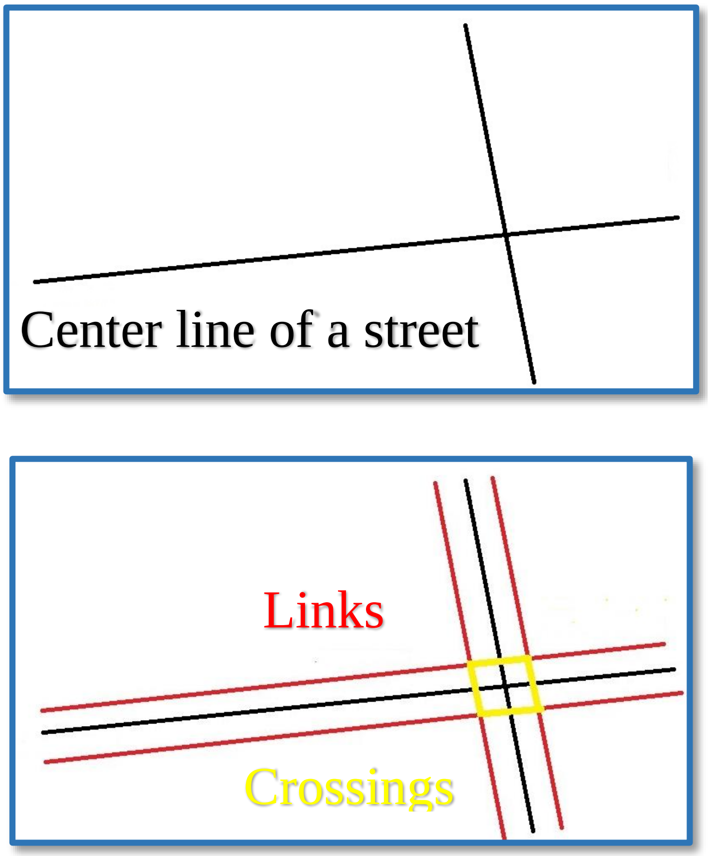


Figure 23 - Creating links and crossings using "copy parallel" tool in ArcGIS

"Vegreferense" omits a number of paths available for pedestrians. OSM has therefore been used to fill this gap as this open dataset contains a relatively large number of paths that have been included in our personal dataset for pedestrians. They are mainly paths through open fields, or they are residential ones. Finally, those paths from "vegreferense" that are not utilized by vehicles or those in which the width is not wide enough remain as a center line.

The following figure shows an example of the final pedestrian network. A higher resolution map can be found in *Map Set Appendix 3A – Base Network*.

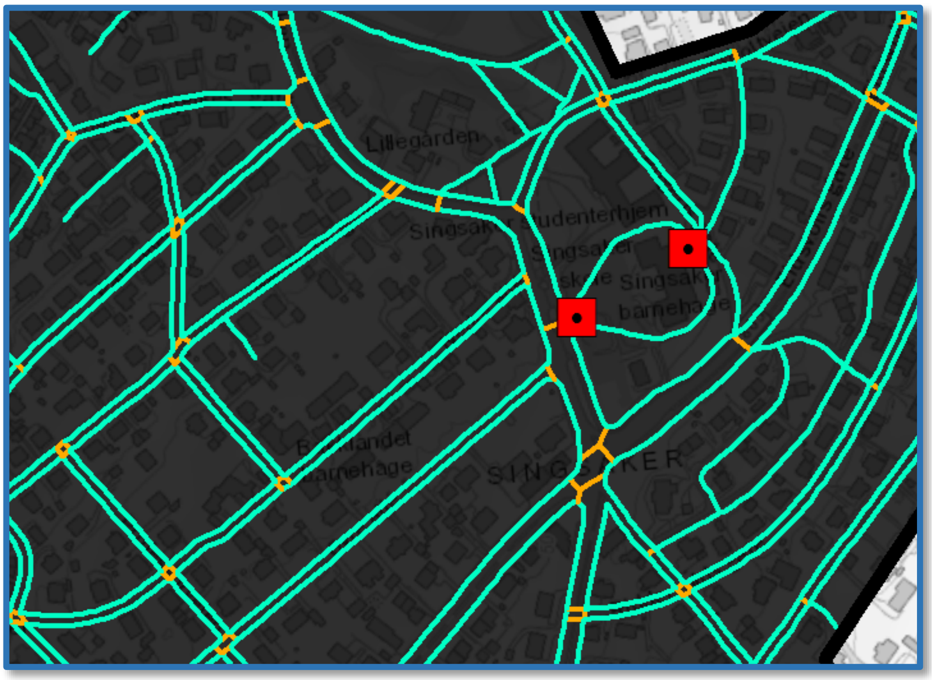


Figure 24 - Pedestrian Network. Blue: Links, Orange: Crossings

Once we have our pedestrian network completed, we must accordingly populate each attribute with the data that will be needed to calculate the impedance safety parameter.

4.2- Populating attribute fields

For each polyline of our network we must add information regarding sidewalks, buffers, lanes, lighting, traffic signals and other features. The primary reason for the project being limited to one school is due to the fact that the process of gathering, preparing and populating the data involved almost two full months of work.

Each of the following datasets can be found in higher resolution in the indicated *Map Set Appendix.*

4.2.1- Sidewalk and shoulder Information (Map Set Appendix 3B)

The datasets "Fortau" and "Vegskulder" from the Norwegian Road Data Bank (NVDB) contain polylines that indicate where sidewalks or shoulders are located and also contain a field with the correspondent width.

With this information, a new column field was added to our personal network indicating first if the link does or does not have a sidewalk, and if so, the width.

The information added to the field SIDEWALK in our personal network has the following values:

- 0 = No sidewalk
- 0’8 = Sidewalk of 0’8 m width or less
- 2 = Sidewalk of 2 m width or less
- 4= Sidewalk of 4 m or less

The information added to the field SHOULDER in our personal network has the following values:

- 0 = No shoulder
- 1 = Shoulder of 1 m width or less
- 2 = Shoulder of 2 m width or less
- 4= Shoulder of 4 m or less

4.2.2- Additional Lanes and buffers (Map Set Appendix 3B-2, 3C and 3D)

There was no dataset found that indicated the existence or otherwise of buffers/furniture zones or parking/cycle lanes. Therefore, several walkabouts were carried out in order to gather this street data and indicate its location on a map.

The results of additional lanes were manually added to our personal network under the fields PARKING LANE and CYCLE LANE, with a value of 0 if there is no additional lane and a value of 1 if there is parking or a cycle lane.

The results of buffer/furniture zones were manually added to the column field BUFFER with the following criteria:

- 0 = No buffer
- 1 = Buffer of 1 m width or less
- 2 = Buffer of 3 m width or less
- 3= More than 3 m of buffer

4.2.3- Signalization (Map Set Appendix 3E)

The dataset “Skiltplate” from the NVDB contains all the children signposts (142), and speed limits (362, 366, 368, 540 and 808). Two fields, SPEED SIGNS and CHILDREN SIGNS, were filled for each polyline with 1 if there are signs on a certain link, and 0 if there are not.

4.2.4- Crossing facilities (Map Set Appendix 3F)

The dataset "Gangfelt" contains information about location crossing facilities for each pedestrian crossing. It is possible to identify which pedestrian crossings have marks, crossing signals, traffic regulation, refuge islands, lighting and raised crossings.

Therefore, the following fields were added: MARKS, CROSS SIGNAL, RAISED, TRAFFIC LIGHTS, REFUGE and LIGHTING, with a value of 1 if there is such a facility and a value of 0 if there is not.

4.2.5- Speed reducing measures (Map Set Appendix 3F)

The dataset called "Fartsdemper" includes all the speed reducing measures in the city, their location and their type. A field called SPEED MEASURES was manually filled with the same information when a link or crossing was close to a speed reducing measure.

4.2.6- Speed limit and actual speed (Map Set Appendix 3G)

The dataset "Fartsgrense" includes the center lines of all the roads and streets of the city of Trondheim. Every road or street has a speed limit according to Norwegian legislation. Therefore, a field called SPEED LIMIT was manually added to our personal street network, including the following speed limits:

- 30 km/h
- 40 m/h
- 50 km/h

No higher speed limit was found in the study area.

As mentioned in *Chapter IV – Feeling of Insecurity Impedance Methodology*, we are going to consider an increase of 10 km/h. A new field called DRIVEN SPEED was created with SPEED LIMIT plus 10 m/h.

It should be mentioned that links that do not carry motorized traffic have been given 0 km/h speed limit.

4.2.7- Traffic Volume (Map Set Appendix 3H)

The dataset "Traffikmenge" includes the center lines of all the roads and streets of the city of Trondheim. Every road or street has the ADT and the percentage of heavy vehicles according to Norwegian registrations.

Therefore, a field called ADT and ADT HEAVY was manually added to our personal street network, including the traffic volume for both light and heavy volumes. The range is between 0 and 18.000 vehicles a day. No higher ADT was found in the study area.

It should be mentioned that links or crossings that do not carry motorized traffic have been given 0 traffic volume.

4.2.8- Walking Time and Length

As the 3D model obtained for the city of Trondheim was a 50 m cell resolution, the length considered has been the 2D measure. This is an approximation of the real walked distance, but the purpose of this project is to present an innovative idea and therefore the differences between a 2D and a 3D model for polylines of around 200 m is low.

The walking time has been calculated by considering a walking speed of 5 km/h and is expressed in seconds.

4.2.9- Link and crossing Impedance (Map Set Appendix 3I)

In order to avoid repetition, please visit *Chapter IV – Impedance Methodology*.

Once our network has been built and filled with all the data required, it is possible to apply the previously mentioned impedance methodology to calculate for each link and crossing its correspondent security impedance cost.

- Appendix 4A – Street Impedance Methodology should be used for links.
- Appendix 4B – Crossing Impedance Methodology should be used for crossings.

It should be mentioned that links representing streets have a crossing impedance (IC) equal to 0 and vice versa.

4.3- Walkabouts

In order to ascertain the reliability of the datasets used to build our network, several walkabouts were carried out around the school zone. A number of errors were corrected and where there was missing data it was added to our personal dataset.

The walkabouts were also useful to validate the results once the impedance cost attribute was calculated, by walking along and crossing the streets with the highest value of impedance.

Notwithstanding, there would still be the need to test the results with parents and children conducting their walkabouts and testing and rating the streets. However, due to the short period available for completion of this Master's project, we are obliged to leave this for future research.

In general, all the datasets were sufficiently accurate enough to provide a reliable source of information.

CHAPTER IV:

Feeling of Insecurity Impedance Methodology

IV) IMPEDANCE METHODOLOGY

1- ORIGINAL IMPEDANCE METHODOLOGY

The original impedance methodology is explained in more detail in the FHWA User Guide SRST *(Brustlin, 2000).* Here we present a brief explanation of this methodology which is based on that developed by Rajeev Karamchedu of CDA Investment Technologies. The impedance indicates how desirable a street is for walking and is directly proportional to how long it takes to walk the link or crossing, and the hazard associated with walking the aforementioned link or crossing. The lower the impedance, the more desirable a link or crossing is for walking.

1.1- Link Impedance

The link impedance is expressed as:

$$I = \left(L \times (3{,}5 \times 60)\right) \times \left(f_{sw} + f_{vol} + f_{sp} + f_{d} + f_{sh} + f_{p}\right) + N$$

Where:

- L = Length of the roadway
- F_{sw} = Hazard associated with sidewalk conditions
- F_{vols} = Hazard associated with volume of heavy vehicles
- F_{sp} = Hazard associated with the speed limit
- F_{d} = Hazard associated with number of driveways
- F_{sh} = Hazard associated with shoulder conditions
- F_{p} = Hazard associated with on-street parking
- N = Hazard associated with other contributing factors

The hazard ratings and the link impedance are different depending on whether one is walking in the direction of the traffic or against it. N refers to other contributing factors that affect the relative desirability of different links. High values of N may be assigned to undesirable links (such as high crime locations) to ensure that they do not appear in the route calculated by the “Safe Route to School” application.

Under the impedance methodology used here, the hazard ratings are on a scale of 1 to 5, where 1 is the least hazardous and 5 is the most hazardous. 0 represents no effect on impedance methodology.

The following table provides an example average hazard ratings collected, which would then be used to calculate impedance. These tables are adapted from tables that Rajeev Karamchedu provided:

HAZARD RATING	WALKING CONDITION	
Pedestrian walking on the edge of the travel lane with: No sidewalk No shoulder	**WITH TRAFFIC**	**AGAINST TRAFIC**
	5.0	4.6
Pedestrian walking on the shoulder with no sidewalk	**WITH TRAFFIC**	**AGAINST TRAFIC**
	4.2	4.0
Pedestrian walking on the sidewalk with no shoulder	WITH TRAFFIC	AGAINST TRAFIC
	1.6	1.4
Pedestrian walking on the sidewalk with a shoulder present	**WITH TRAFFIC**	**AGAINST TRAFIC**
	1.2	1.0

Table 6: Hazard ratings (Brustlin, 2000)

Regarding the speed factor impedance we have:

Speed Limit (km/h)	Speed Factor (f_{sp})
0-25	1.4
25-40	1.8
40-55	2.6
55-70	3.2
>70	4.0

Table 7: Speed factor ratings (Brustlin, 2000)

1.2- Crossing Impedance – Signalized Intersections

The crossing impedance is calculated as follows:

$$I = \big(W \times (3{,}5 \times 60)\big) \times (f_{CW} + f_{SP} + f_{PS} + f_P + f_{OW} + \log V) + N$$

In order to calculate the crossing impedance of streets at signalized intersections, the following factors are considered:

- W = Width of the crossing
- F_{CW} = Presence of pedestrian crossings markings
- F_{SP} = Vehicle speed at the crossings
- F_{PS} = Pedestrian signals
- V = Crossing volumes
- F_P = Parking lane close to pedestrian crossing
- F_{OW} = one-way or two-way street
- N = Other contributing factors

The values of the factors and the crossing impedance are different for crossing one-way and two-way streets.

1.3- Crossing Impedance – Unsignalized Intersections

The crossing impedance is calculated as follows:

$$I = \big(W \times (3{,}5 \times 60)\big) \times (f_{CW} + f_{SP} + f_G + f_P + f_{OW} + \log V) + N$$

In order to calculate the crossing impedance of streets at signalized intersections, the following factors are considered:

- F_{CW} = Presence of pedestrian crossings markings
- F_{SP} = Vehicle speed at the crossings
- F_G = Available gaps
- V = Crossing volumes
- F_P = Parking lane close to pedestrian crossing
- F_{OW} = one-way or two-way street
- N = Other contributing factors

The values of the factors and the crossing impedance are different for crossing one-way and two-way streets.

2- ALTERNATIVE IMPEDANCE METHODOLOGY

Here we will present a number of changes to the methodology previously explained. The purpose of these changes is to include new considerations that have to be taken into account, such as the presence of buffers, actual speed, and lighting conditions.

Another consideration is that the conditions regarding the infrastructure, the speed limit and traffic flow were weighted equally. As speed is the main risk factor followed by the traffic volume, these three parameters will be weighted accordingly by using an MCA methodology.

The original methodology calculated an impedance factor that has no units and therefore it is difficult to classify or compare this with other cases. In addition, here we will try to put forward an index that may be useful for classifying different school boundaries and to prioritize where investments should be made first.

The new impedance methodology will also be proportional to the time spent in walking along the link or over the crossing.

2.1- Behavioral Impedance Taxonomy

Behavioral impedance (BI) refers to all the different universal features that pedestrians might encounter on their routes. Most of the models indicate routes by using the shortest route as the main criteria, when sometimes the best path is one that exists regardless of either distance or time (Hernane et al., 2001).

Recker claimed that "*to extent that travel time is not merely just a surrogate for the actual economic cost of travel, the implication is that the time savings can and will be transformed by the traveler into something of intrinsic value – ostensibly either in more time spent on performing activities of economic, or other, value, or in increasing the 'capture space' of alternative locations for such activities*". (Recker et al., 2001)

Schwartz also highlighted impedance factors for pedestrians such as comfort, safety, elevation changes, traffic crossings and crowding. All these factors are considered in BIT (Schwartz et al., 1999).

The Behavioral Impedance Taxonomy from the pedestrian's perspective is going to help us to model the cost impedance (*safe perception parameter S*) used in our network, along with time impedance. The proposed taxonomy offers support in solving problems such as data needed and choosing the best route. (Hernane et al., 2001)

We will use this scheme to model our own safe perception parameter. It means that not all these factors will be considered and only those which might have an important influence on traffic safety will be taken into account.

In the following table we indicate the type of data that we will try to collect:

Level 1	Level 2	Level 3	Level 4
Behavioral Impedance Domain	**Environment**	**Topographic**	**Permanent**
		Weather	-
	Temporal	**Work-day**	**Peak hour**
		Weekend/Holyday	-
		Atypical day	-
	Network	*Incidental*	-
		Infrastructure	**Facility – Accessibility - Connectivity**
	User	**Personal**	**Comfort**
		Professional	-
	Socio – Politic - Economic	**Safety**	**Traffic flow - Reliability**
		Security	**Dangerous zones**
		Policy	-
		System	-

Table 8 – BIT for our model

Now, under this domain, we have to identify the factors that will weigh the impedance for each link and crossing in our network.

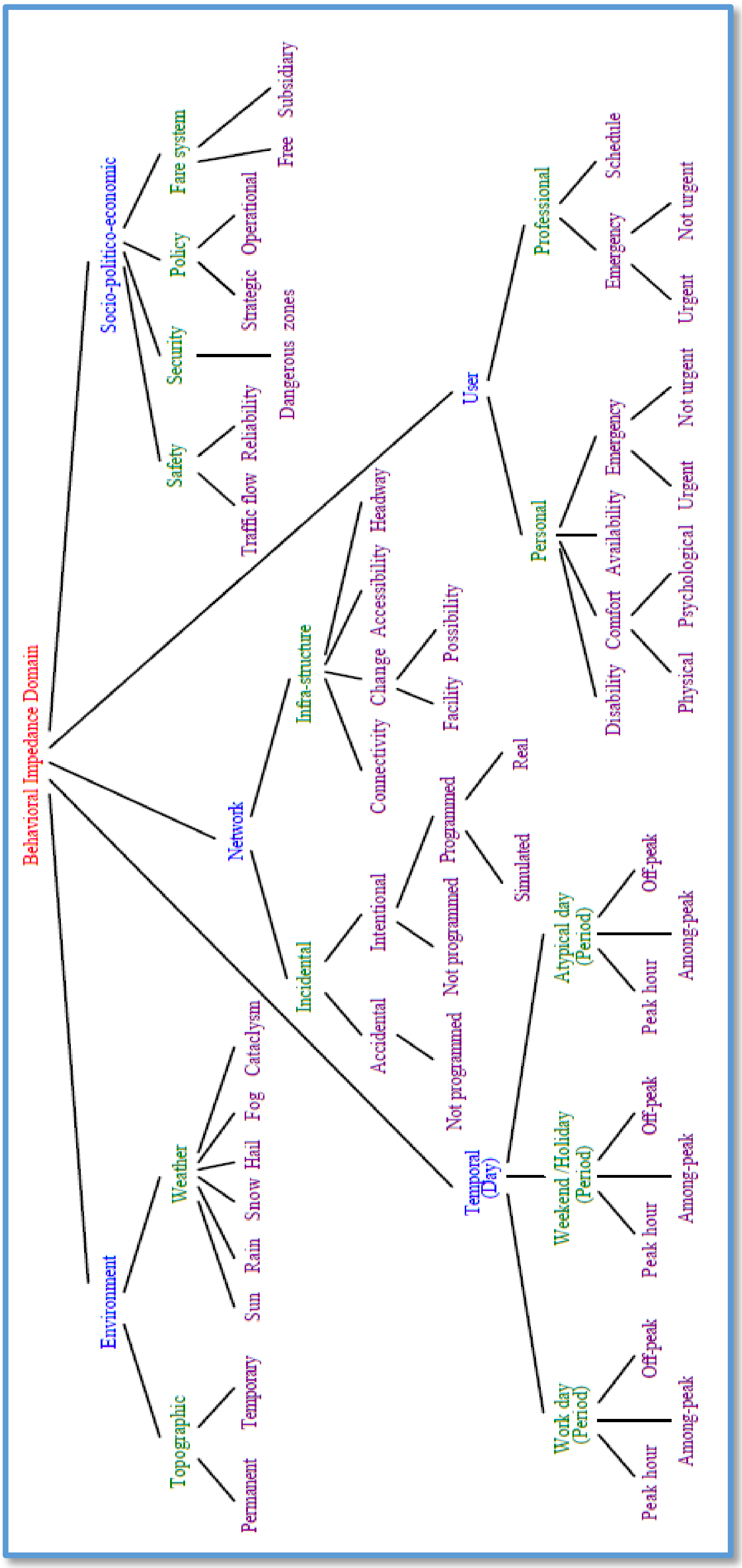


Figure 25 - Behavioural Impedance Domain (Hernane et al., 2001)

A study conducted in 2009 (Asma Ali and Cristei, 2009) was undertaken to predict Level of Service (LOS) ratings of urban streets for the pedestrian facilities based on the user's perception of the quality of service. The results of the correlation analysis indicated sidewalk width, number of traffic lanes, presence or absence of barriers between the pedestrians and the roadway traffic, and the same directional traffic volume as the significant variables influencing the comfort level of the pedestrian. The correlation analysis showed that on urban streets with (greater than 5 ft wide) sidewalks greater than 5 ft in width and barriers between the pedestrian and vehicular traffic, pedestrians have higher levels of comfort. In contrast, higher numbers of traffic lanes and heavier traffic volume cause impedance to the safe movement of the pedestrians

Some other studies have examined the street features that influence the greatest number of parents' perceptions of safe routes to school. Streets without sidewalks or with obstacles as well as intersections with important roads were considered to be unsafe (Evers et al., 2014). The number of motorized vehicles and the number of street crossings seem to have an effect on parents' safety perception as well (Larsen et al., 2013).

More people walking or cycling along a route appears to reduce driving speed according to one study conducted in 2015 (Jacobsen, 2015). Finally but no less important, intersections with signals, median or refuge islands and guards at crossings are considered as positive (Issidro et al., 2013).

Vehicle speed seems to be the most important factor among traffic conditions, according to one study conducted in 2010 "*For pedestrians, this is typically measured in terms of the speed of the vehicle at the point of impact with the pedestrian. Pedestrians are a particularly vulnerable road-user group, with small changes in impact speed potentially having a large effect on the risk of fatal injury*" (Richards et al., 2010).

"*At low speeds (e.g., below about 15 mph), risks are low and increase relatively slowly with small increments in speed. At impact speeds below 15 mph, most pedestrians who are struck (about 91%) do not sustain AIS 4 or greater injuries, and very few (about 2-5%) die. However, as speeds increase beyond this range, small changes in speed yield relatively large increases in risk*" *(*Brian C. Tefft, 2011).

"Higher traffic volume at an intersection translates to decreases in walking. A higher number of vehicles could produce an unpleasant walking environment. From a safety standpoint, a higher traffic volume could also be associated with an increased risk of pedestrian injury or death (…) Traffic volume related to mode choice for the journey to school, and the null finding for traffic mix suggests that, overall, volume is potentially more problematic than vehicle type in regards to mode choice. That is not to say that vehicle type is not important in the context of pedestrian injury or death. Evidence from this study supports the reduction of the numbers of vehicles around schools." (Larsen et al., 2013)

According to one studio conducted in 2003 in Seattle, WA, pedestrians hit by heavy vehicles have more chances of been severely injured (31 %) than by light vehicles (25 %) for all group ages. (Henary et al., 2003).

Therefore, we have selected a total of 22 factors. The type of data will be both quantitative and qualitative and the sources a combination of walkabouts and data provided by NPRA. Therefore, these factors can be divided in three main groups:

- Links
- Pedestrian crossings
- Traffic

Factors in Feeling of Insecurity Impedance Methodology			
Group	**Factor**	**Type of data**	**Source**
Streets (Links)	Barriers	Qualitative	Walkabouts
	Buffers	Qualitative	Walkabouts
	Sidewalks	Qualitative	Walkabouts / NPRA
	Shoulder	Qualitative	Walkabouts / NPRA
	Parking lane	Qualitative	Walkabouts
	Bike lane	Qualitative	Walkabouts
	Signal posts	Qualitative	Walkabouts / NPRA
	Lighting	Qualitative	Walkabouts / NPRA
Pedestrian crossings	Signal posts	Qualitative	Walkabouts / NPRA
	Zebra crossings	Qualitative	Walkabouts / NPRA
	Pedestrian phasing	Qualitative	Walkabouts / NPRA
	Traffic Guards	Qualitative	Walkabouts
	Median / refuge islands	Qualitative	Walkabouts / NPRA
	Speed bumpers	Qualitative	Walkabouts
	Lighting	Qualitative	Walkabouts / NPRA
	Pedestrian crossing above/under major road	Qualitative	Walkabouts / NPRA
Traffic	Vehicle speed	Quantitative	Own measurements / NPRA
	AADT	Quantitative	NPRA
	% Heavy vehicles	Quantitative	NPRA
	One/two ways	Qualitative	Walkabouts/NPRA
	Speed limit	Quantitative	NPRA
	Type of road	Qualitative	NPRA

Table 9 – Factors in feeling of insecurity impedance methodology

The Feeling of Insecurity Impedance Index utilizes two main terms:

- Exposure: Total time walking along a link or crossing a street
- Safe perception: Subjective safe perception while walking along a link or crossing a street.

$$I = Exposure \times Safe\ Perception$$

Exposure will be easy calculated by measuring the total length of a certain link or crossing and dividing it by a walking speed of 5 km/h (*walking time*).

Safe perception is a non-objective parameter that will take into account all the factors mentioned above. In order to measure the safe perception, a Multicriteria Analysis (MCA) will be performed along with an Analytic Hierarchy Process.

2.2- Multicriteria Analysis

"Decision making is a selection process between alternative action courses, based on different criteria, in order to reach one or more objectives" (Simon, 1960). A decision making process include the following steps:

- Situation analysis
- Identifying aspects and formulating a problem to evaluate the solutions
- Decision making model
- Sensitive analysis

When it comes to analyzing complex problems, the judgment of only one person could be insufficient. Because of this, it should be extended to discussion with other parties who, thanks to their experience in this field, can help to structure the problem and to evaluate the alternatives more efficiently. It is here that Multi-criteria Analysis (MCA) is indicated as a helpful tool for decision making. These methods are not for finding the optimal solution, but are based on the decision-making agent's preferences and on predefined objectives to:

- Choose the best alternatives
- Accept alternatives apparently "good" and discard those apparently "bad"
- Generate a "ranking" among the different alternatives from "the worst" to "the best"

The number of alternatives could be infinite (*Multiobjective decision making*) or finite (*Multicriteria decision making*). The latter are the most frequent problems that we found in the real world and these are the ones considered in this study. The characteristics of Multicriteria decision making are:

- A finite stable number of alternatives, perfectly identified but not necessary completely known in all their quantitative or qualitative features.
- A criteria tree which allows the evaluation of every single alternative according to the weights assigned by the decision-making agent
- A matrix impact which contains the evaluation of each alternative as well as their scores and ranking.
- A global preference model that creates a hierarchy of judgments, and classifies or ranks them in order to determine the solution with the best evaluations.
- A decision-making process in which discussion and exchange between participants are performed

Under the Multicriteria analysis methodology, two methods will be applied in our methodology:

2.2.1- <u>Multiattribute Utility Function</u>

A utility partial function is determined for each attribute and afterwards they are aggregated in a utility function (by adding or multiplying them altogether). With this method we get a complete ranking of all the alternatives.

The assignation of weights are defined according to one method developed by Gomez Orea (Domingo Gómez and Mauricio Gómez, 2011).This is a method called "classification per scalar degrees" and it is very suitable for 'liker questionnaires' where people are asked to rank elements on a given scale. In our case, the scale which has been used is from 1 to 5 for the different infrastructure features.

Under this methodology, in one study conducted in 2011 measuring the walkability of the streets, the methodology is summarized (Ballester, 2011): "T*he weighted or normalized value that a respondent i assign to the element e it is obtained by the expression":*

$$V_{ei} = \frac{E_{ei}}{\sum_{e=1}^{n} E_{ei}}$$

"Where ***E_{ei}*** *is the value in the proposed scale that the participant* ***I*** *assigns to the element or criteria* ***e****. As a weighting value of the element either the mean or the sum it is used."*

$$V_{e} = \frac{\sum_{i=1}^{m} V_{ei}}{\sum_{i=1}^{m} \sum_{e=1}^{n} V_{ei}}$$

"It must be observed that the denominator's value matches with the number of judges or participants, in a way that:"

$$\sum_{i=1}^{m} \sum_{e=1}^{n} V_{ei} = m$$

"To better illustrate and understand the method proposed by Gomez Orea, an example of using a 1 to 10 scale with four judges or responses and five criteria or elements to analyze it if further described. The table below represents the obtained example results:"

n elements	m judges / respondents			
	1	2	3	4
1	3	4	4	4
2	2	3	3	2
3	10	9	8	9
4	4	5	5	3
5	6	5	6	4
ΣE_{ei}	25	26	25	22

Table 10 - Gomez Orea MCA methodology (Ballester, 2011)

"In such an example case, the values that a respondent i assign to the element e are first weighted or normalized by applying the previously described (Vei) formula. The obtained results of such a process are illustrated in the following table:"

n elements	m judges or respondents			
	1	2	3	4
1	3/25 = 0,12	4/26 = 0,15	4/25 = 0,16	4/22 = 0,18
2	2/25 = 0,08	3/26 = 0,12	3/25 = 0,12	2/22 = 0,09
3	10/25 = 0,4	9/26 = 0,34	8/25 = 0,32	9/22 = 0,41
4	4/25 = 0,16	5/26 = 0,19	5/25 = 0,2	3/22 = 0,14
5	6/25 = 0,24	5/26 = 0,19	6/25 = 0,24	4/22 = 0,18

Table 11 - Gomez Orea MCA Methodology (Ballester, 2011)

"Based on this (intermediate) weights' average, the final weights are assigned to all of the ***n*** *elements analyzed by* ***i*** *judges or respondents by applying the previously described (*V_e*) formula. The obtained final weights for all of the* ***n*** *elements proposed in the example are listed below:"*

$$V_e = \frac{\sum_{i=1}^{m} V_{ei}}{\sum_{i=1}^{m}\sum_{e=1}^{n} V_{ei}} \quad \left\{ \begin{aligned} V_1 &= \frac{0{,}12+0{,}15+0{,}16+0{,}18}{4} = 0{,}15 \\ V_2 &= \frac{0{,}08+0{,}12+0{,}12+0{,}09}{4} = 0{,}10 \\ V_3 &= \frac{0{,}4+0{,}34+0{,}32+0{,}41}{4} = 0{,}37 \\ V_4 &= \frac{0{,}16+0{,}19+0{,}2+0{,}14}{4} = 0{,}17 \\ V_5 &= \frac{0{,}24+0{,}19+0{,}24+0{,}18}{4} = 0{,}21 \end{aligned} \right.$$

2.2.2- Analytic Hierarchy Process

This method was developed in 1980 by Thomas Saaty and consists of formulating a complex problem using a scheme, and to build a Hierarchy Model that basically has three levels:

- Goal or objective,
- Criteria
- Alternatives.

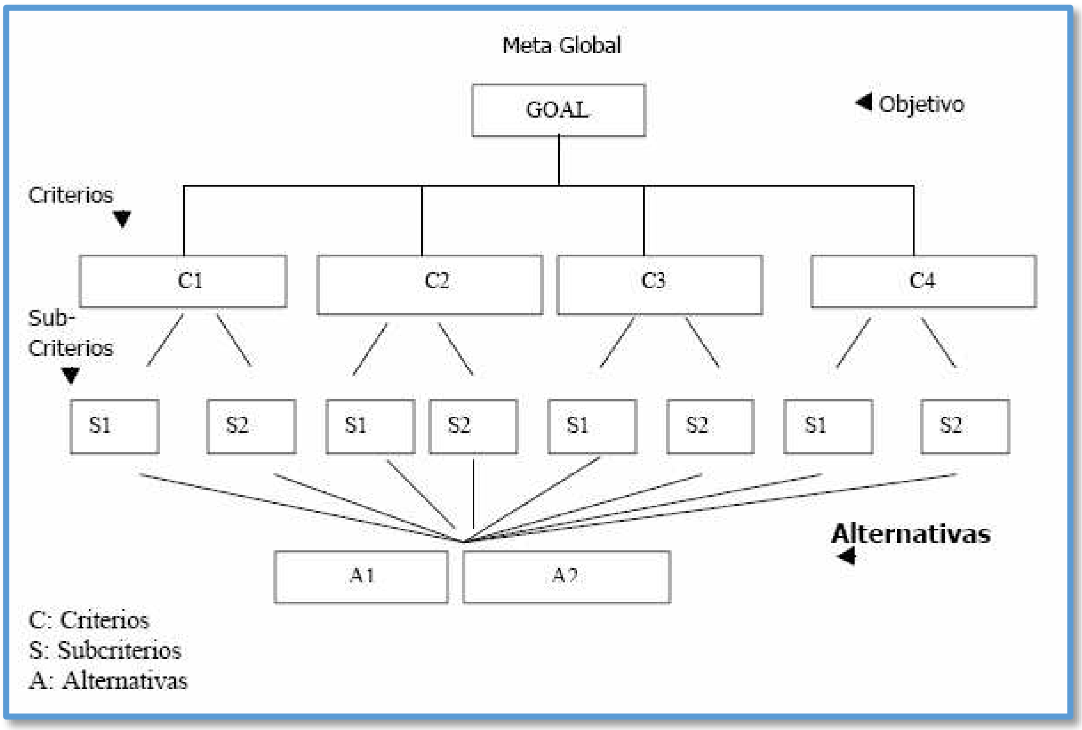


Figure 26 – Analytic Hierarchy Process

Once our model has been built, the next step is to compare one-by-one the different criteria and elements, giving them numeric values with regards to the participant's judgment. In order to make these comparisons, preference scales are used according to importance or preference ranging from 1 to 9.

Pair value compared ij	Comment
1	Criteria i and j are equally important
3	Criteria i is slightly more important than j
5	Criteria i is more important than j
7	Criteria i is strongly more important than j
9	Criteria i is absolutely more important than j
2,4,6,8	Intermediate values between two judgments
Increases of 0'1	Intermediate values for grading judgments

Table 12- Saaty Scale

2.2.3- Web-based questionnary

Safe perception has been evaluated following a method of self-report using a web-based questionnaire that includes questions regarding the environment within the school boundary. Now we are going to explain this questionnaire in more detail.

For our project an anonymous online questionnaire has been developed using "Typeform". Typeform is a web-based platform for collecting and sharing information, in a conversational, human way. Online forms are boring – Typeform (fix) resolves that issue. Beautifully designed, asking one question at a time like a real conversation, they are engaging and fun to complete.

This combination gives Typeform great completion rates, meaning you get better results. The company was founded by David Okuniev and Robert Muñoz in 2012 and they now lead a team of people in Barcelona, Spain. Typeform is backed by fantastic investors – Index Ventures, Point Nine Capital, RT Adventures, and Connect Ventures.

The questions are divided in different groups:

- Personal non-sensitive information questions: These questions are addressed to collect information such as:
    - Field of studies
    - Student/Professional/Professor
    - Parent or Non-parent
    - Driving License
- General transport infrastructure question: We want to determine what it does have more relevance in people's safe perception in order to weigh them accordingly between:
    - The streets features (links)
    - Pedestrian crossings
    - Traffic conditions
- Street features questions: These questions are addressed to find and weight the safest features along the streets that pedestrian might come across in their daily journeys. The ratings are ranged from 1 (low safe perception) to 5 (High safe perception).

- Pedestrian crossing features questions: These questions are addressed to find and to weigh the safest features when it comes to crossing streets that pedestrian might come across in their daily journeys. The ratings are ranged from 1 (low safe perception) to 5 (High safe perception).
- Traffic conditions questions: We want to determine what it does have more relevance in people's safe perception in order to weigh them accordingly between:
    - Vehicle speed
    - Amount of heavy vehicles
    - Total amount of traffic volume
- School Zone questions: These questions are addressed to find the measures that people have a preference for when implementing them in the school zone.

The questionnary has been available at the following link during the case study:

(Spanish Version) - (García-Torres Fernández, 2017a)

(Norwegian Version) - (García-Torres Fernández, 2017b)

2.2.4- Participants involved – Expert judgment

In order to ensure validity and reliability the opinions of experts regarding their personal perception of safety have been considered. On this basis, the experts are considered to be those adult respondents (between 18 – 60 years old) who either:

- Have a high level of education
- Have already or have been a parent
- Have a driving license

All the other participants that do not fulfill at least one of the conditions mentioned above are considered non-experts or general users. The questionnaire has been sent to university departments, school head teachers, and parents from both Spain and Norway via e-mail.

2.2.5- Respond attendance

Within the overall number of responses, only those considered to be expert responses have been taken into account. The total number of valid respondents has been 63 (Out from a total respondents number of 143).

Opinions from different groups have been weighed differently:

- Civil Engineering Professors: 40 %
- Parents: 35 %
- Civil Engineering Students: 15 %
- Rest: 10 %

Opinions from Civil and Transport Engineering as well as parents are highly considered, the first group due to their vast knowledge of traffic engineering and road planning and design and the second group due to their concern about the different features that their children might encounter along their routes to schools.

Appendix 4C – Web Questionnary contains a copy of the survey as well as the results.

2.3- The Feeling of Insecurity Impedance Index

Here we present the Innovative Impedance Index on which this Master's Thesis is based. Our network consists of a set of polylines that represents the pedestrian network of the city of Trondheim. There are two main types of polylines:

- Links
- Pedestrian crossings

As mentioned before, the impedance index has two main expressions of terminology:

- Exposure: Total time walking along a link or crossing a street. It could be measured in seconds, minutes or hours.
- Safe Perception: Can be defined as the subjective safe perception while walking along a link or crossing a street. The range of this value goes from 0 (*Feeling of security*) to 1 (*Feeling of insecurity*).

$$I_S = Exposure \times Safe\ Perception$$

This is the innovative Index that will help us to measure streets and crosswalks. The impedance index (IS) unit is "S". The basic unit is 1 Ss and represents one second with a insecure feeling equal to being walking along a link with an impedance of 1. It can be expressed in seconds, minutes or hours. If time is expressed in seconds: Ss, in minutes Sm, and in hours Sh.

This is a manner in which to both classify different streets and to utilize as a method of comparison. It is also an index that measures how much time a pedestrian has a feeling of insecurity equal to being walking along a street with the highest impedance. For example, let us imagine a pedestrian walking along a highway (*figure 27*), and another along a pedestrian street (*figure 28*).

The "Safe Perception" S in figure 27 is "1" (*feeling of complete insecurity*), while in figure 28 it is "0" (*feeling of complete security*). If a pedestrian has to walk a distance of 1 km with a walking speed of 5 Km/h along both links, it will take them 720 seconds (12 minutes) and the I_S is:

$$\boldsymbol{I_S\ (Figure\ 27)} = \frac{1\ km}{5\ \frac{km}{h}} \times 1S = 0{,}2\ S_h = 12\ S_m = \boldsymbol{720\ S_s}$$

$$\boldsymbol{I_S\ (Figure\ 28)} = \frac{1\ km}{5\ \frac{km}{h}} \times 0S = 0\ S_h = 0\ S_m = \boldsymbol{0\ S_s}$$

The results state that a pedestrian as in figure 27 would be walking for 720 seconds (12 minutes) out of 720 seconds with a feeling of total insecurity, while a pedestrian as in figure 28 will be walking along the whole street without even thinking about his safety for one second out to 720. Let us now give an intermediate example like the one we can found in figure 29 and in figure 30:

Figure	Distance	Speed	Walk Time	S	Is (sec)	Is (min)	Is (h)	Insec. Feeling
29	1 km	5 km/h	720 s	0,147	105,84	1,764	0,0294	**14,7 %**
30	1 km	5 km/h	720 s	0,004	2,88	0,048	0,0008	**0,4 %**

Table 13 - Example intermediate examples

Figure 27 - Pedestrian walking along a highway

Figure 28 -Pedestrian walking along a pedestrian street

Figure 29 - Pedestrian walking on a narrow sidewalk

Figure 30- Pedestrians walking on a wide sidewalk

The Safe Perception Parameter S will be explained in more detail in the following section. At present, we are simply going to state that S takes into account variables such as the presence of sidewalks, buffers, bike lanes, vehicle speeds and traffic volume.

As we can see, figure 29 seems to have a negative effect on the perception of security of pedestrians while figure 30 presents almost no impedance at all. As a result of these calculated impedances we could now seek measures to implement in order to lower the % of feeling insecure. A deep analysis could identify for each link or road which factor has the highest impedance and therefore implement a measure that reduces the impedance in that factor.

To summarize, here are the four examples presented:

Figure	Distance	Speed	Walk Time	S	Is (sec)	Is (min)	Is (h)	Insec Feeling
27	1 km	5 km/h	720 s	1	0,2	12	720	**100 %**
28	1 km	5 km/h	720 s	0	0	0	0	**0**
29	1 km	5 km/h	720 s	0,147	105,84	1,764	0,0294	**14,7 %**
30	1 km	5 km/h	720 s	0,004	2,88	0,048	0,0008	**0,4 %**

Table 14 - Examples of Feeling of Insecurity Impedance Index

If we choose to lower the impedance on the example presented in Figure 29, we should look at the impedance values. If we implement two measures such as wider sidewalks up to 3 m and speed bumpers that reduce actual speed from 50 km/h to 30 km/h, we would obtain a new value for S and thus the results would be modified as follows:

Figure	Distance	Speed	Walk Time	S (old)	S (new)	Insecurity (old)	Insecurity (new)	Diff
29	1 km	5 km/h	720 s	0.147	0,09	14,7 %	**0,9 %**	**13,8 %**

Table 15 - Example countermeasures

Given a route walked by a pedestrian, the total impedance is the sum of all the links and pedestrian crossings that the pedestrian walk along:

$$I_S = \sum I_L + \sum I_C$$

Where:

- I_L = Link impedance
- I_C = Pedestrian crossing impedance

As a result, this methodology helps to identify the links and crosswalks with the highest impedances and to suggest where to focus on the measures that should be implemented. The impedance of each type of polyline is explained in the following chapter.

We can make the following scheme to better illustrate the methodology:

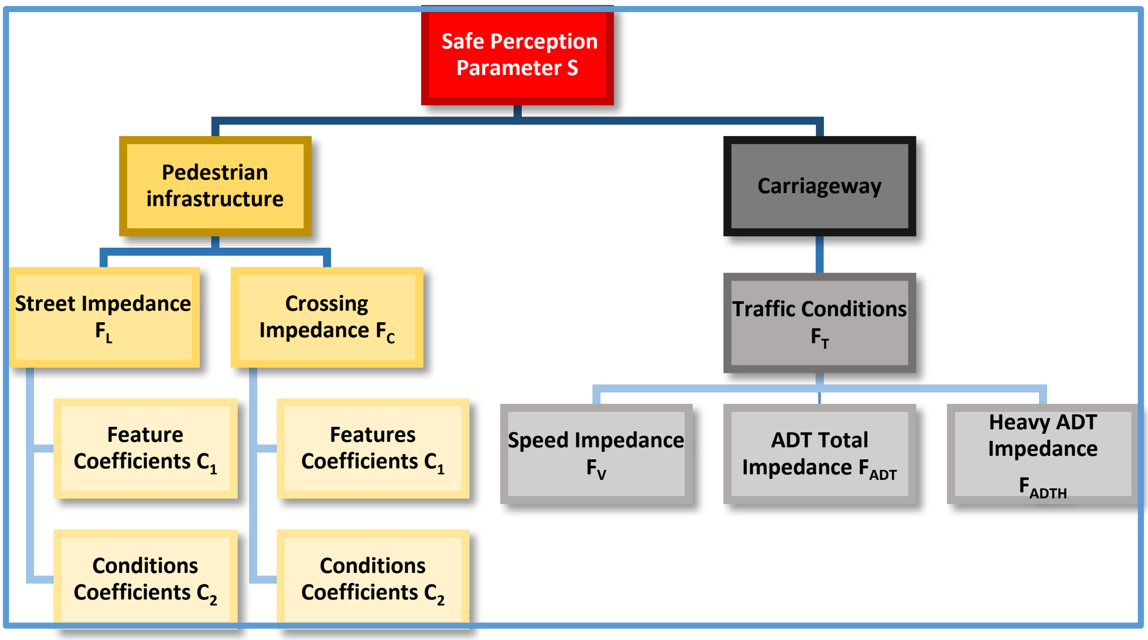


Figure 31 – Feeling of Insecurity Impedance Index scheme

2.4- Link Impedance Index

$$I_L = \frac{L}{V_w} \times S = \frac{L}{V_w} \times (AF_L + BF_T)$$

Where:

- I_L = Feeling of Insecurity Impedance Index for a given link
- L = Length in meters
- V_w = Walking speed
- A, B = Weight coefficients
- F_I = Link infrastructure impedance
- F_T = Traffic impedance

Now we are going to explain each of the main factors in detail.

2.4.1- Weight coefficients

The original impedance methodology equally weighted the infrastructure where pedestrians walk or cycle, and the conditions where traffic flows. However, it could be that traffic conditions or the infrastructure are perceived differently by road users, and thus, they have a preference with regards to where to walk.

Therefore, collecting information with surveys will give us the preference of the experts. Under the MCA and AHP methodology explained before, these coefficients are calculated as follows:

1st element more dangerous					
		Frequency	**Percentage**	**Valid**	**Accumulated**
Valid	**Traffic volume and vehicle speed**	16	29,1	29,1	29,1
	The streets	9	16,4	16,4	45,5
	The pedestrian crossings	30	54,5	54,5	100
	Total	55	100	100	

Table 16 - Link weight 1st

2nd element more dangerous					
		Frequency	Percentage	Valid	Accumulated
Valid	Traffic volume and vehicle speed	19	34,5	34,5	34,5
	The streets	17	30,9	30,9	65,5
	The pedestrian crossings	19	34,5	34,5	100
	Total	55	100	100	

Table 17 - Link weight 2nd

Therefore we can build the following table with the score and weight for TRAFFIC and LINKS. The score is calculated by squaring frequencies:

	1º Rank	2º Rank	3º Rank	TOTAL	Weight
TRAFFIC	256	361	400	1890	53%
LINKS	81	289	841	1662	47%
			SUM	3532	100%

Table 18 – Score and Weigh coefficients for Links

Therefore the values for the weight coefficients are:

- A = 0,47
- B = 0,53

2.4.2- Link infrastructure impedance F_L

This factor refers to the quality of the infrastructure for walking purposes. Wide sidewalks with buffers filled with trees or benches are given the best scores while streets without sidewalks or additional lanes are considered as having high impedance.

The rating of FL is from 0 (No impedance) to 1 (High impedance). In order to provide a link with a score, the existence of buffers, sidewalks, additional lanes for bicycles or parking and lighting have been taken into account. To better illustrate this, here we present two real examples:

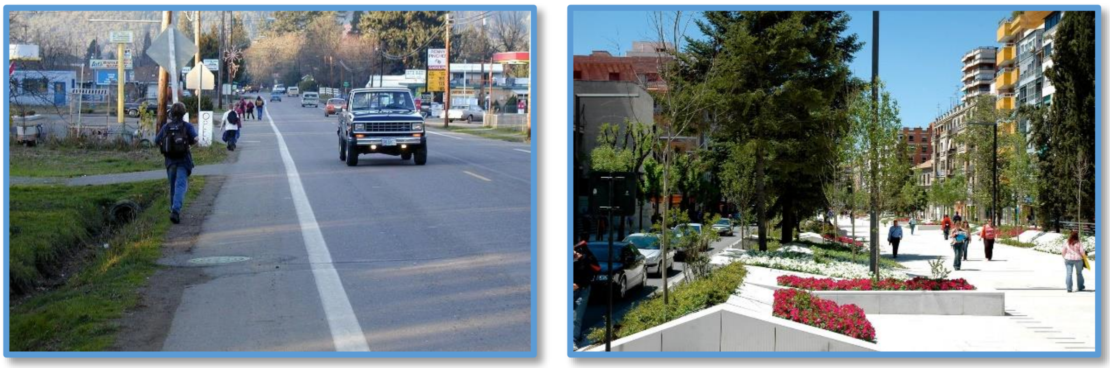


Figure 32 – Left: Link Impedance F_T = 1, Right: link Impedance F_T = 0

Once analyzed the results from the Web-Questionnary we can start weighing the different factors. Under the MCA and AHP methodology previously explained, the following table shows one example of the results obtained, corresponding to a Collector Street (Secondary Link) with additional lanes:

TIME	Signalization		Sidewalks		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C_1	Score	C_1	Score	C_1	Score	C_1	Score	C_1
NIGHT	14 %	0,14	22 %	0,22	22 %	0,22	22 %	0,22	9 %	0,09
DAY	17 %	0,17	27 %	0,27	28 %	0,28	27 %	0,22	-	-

Feature Group	Condition	Score	C_2
Signalization	No school or speed signals	0	**1**
	Speed Signals	50 %	**0,5**
	School signals	50 %	**0,5**
	Both	100 %	**0**
Sidewalks	No sidewalk	0	**1**
	Narrow < 2m	33 %	**0,66**
	Normal 2-4 m	66 %	**0,33**
	Wide > 4 m	100 %	**0**
Buffer / Barriers	No buffer / barrier	0 %	**1**
	Narrow buffer < 1 m	33 %	**0,66**
	Normal buffer 1-3 m	66 %	**0,33**
	Wide buffer > 3 m	100 %	**0**
	barrier	100 %	**0**
Additional Lanes	Usually unoccupied	33 %	**0,66**
	Often occupied	66 %	**0,33**
	Normally occupied	100 %	**0**
	Bike lane	50 %	**0,5**
Lighting	No	0	**1**
	Poor conditions	50 %	**0,5**
	Good conditions	100 %	**0**

Table 19 – Example FL Tables

The value of F_L for each polyline is calculated as follows:

$$F_L = \sum f_l = \sum C_1\, C_2$$

Where:

- C_1 = Feature coefficient. It weighs the different features along a link according to the expert's preference.
- C_2 = Condition feature. It gives a score according to the condition of the feature.

Not all the factors will be used for all the pedestrian links. First, we will check which features should be included for each street according *Chapter II: Streets and Pedestrian Crossings – Definition and Classification*. This means that we are going to have weight coefficients for different features according to each kind of road.

In the *Appendix 4A – Street Impedance Methodology***,** material is provided with which to calculate the impedance for each kind of street.

Concept Design		
Speed limit	*50 km/h*	*30 – 40 km/h*
ADT range	*0 – 15.000 ADT*	*0 – 15.000 ADT*
Buffer and barriers	*Recommended*	*Recommended*
Sidewalks	*Minimum 2m*	*Minimum 2m*
Bike lanes	*Required*	*Required if ADT > 4.000*
Parking lanes	*No permitted*	*Permitted if < 8.000*
Bike and Parking lanes	*No*	*Permitted if ADT < 8.000*
Travel lanes	*2*	*2*
Accessibility	*Limited driveways*	*Limited driveways*

Table 20 - Example Concept Link Design

2.4.3- Traffic conditions impedance F_T

The traffic conditions impedance is calculated as follows:

$$F_T = D \cdot F_V + E \cdot F_{ADT} + F \cdot F_{ADTH}$$

Where:

- D = Speed weight
- F_V = Vehicle speed impedance
- F_{ADT} = ADT impedance
- F_{ADTH}= Heavy ADT impedance
- E = Total ADT weight coefficient
- F = Heavy vehicle ADT weight coefficient

Speed Impedance

We have seen in the literature that vehicle speed is probably the most important factor that affects pedestrian safety.

We are going to score the different vehicle speeds according to risk fatality and risk of severe injury. The following graph shows the risk of pedestrian fatality as a function of speed:

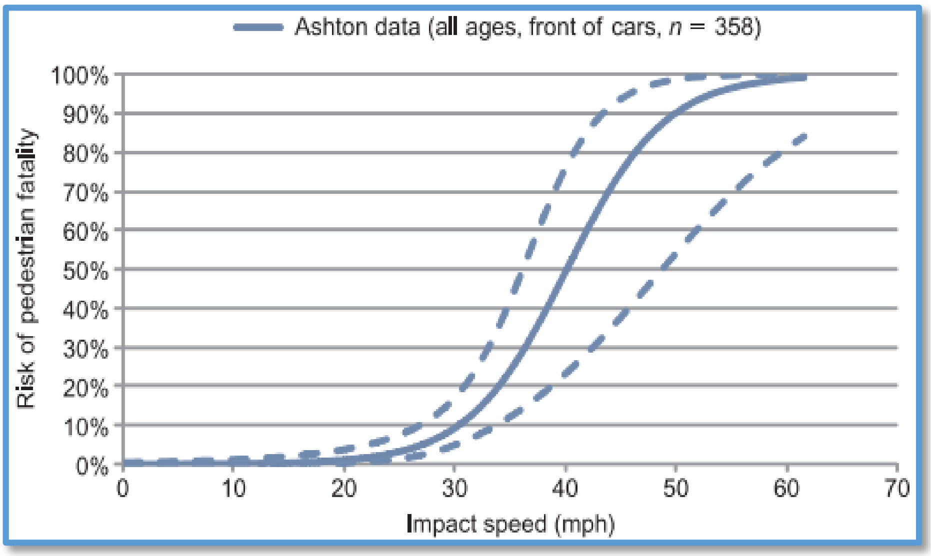


Figure 33 - Risk of pedestrian fatality (Richards et al., 2010)

The next graph shows the risk of severe injury in relation to speed:

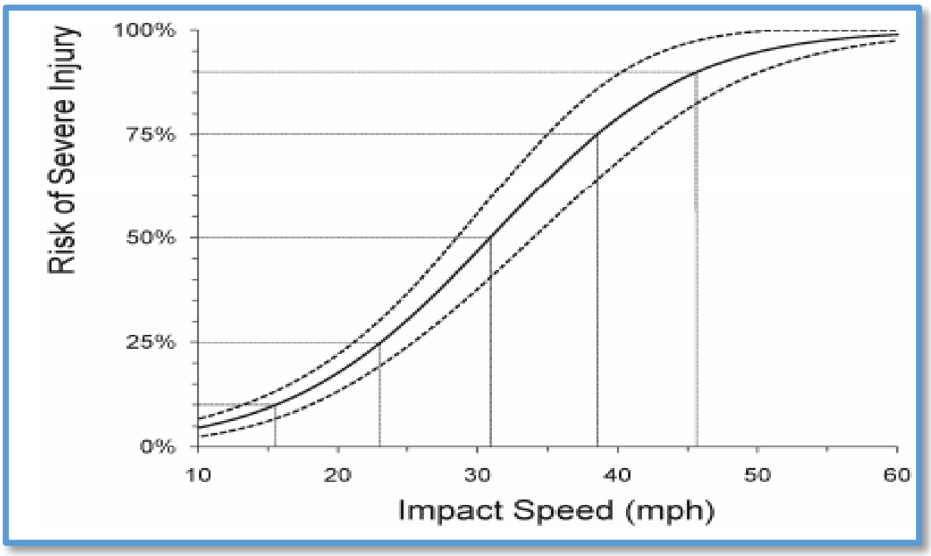


Figure 34 - Risk of severe injury (Tefft, 2013)

Accuracy could be improved if we consider actual speed instead of the speed limit according to previous research. One study conducted in 2005 (Jonsson, 2005) demonstrated that accident models could be improved by using actual speed instead of speed limit. The results shown an increase of 5-10 km/h vehicle speed in urban links. Despite the fact that this results depends on measurements and local features, we will assume an increase of the same kind.

With this background, we will use an increase of 5-10 km/h above speed limit instead of using just the speed limit, used in the original impedance methodology. Thus, the values of F_V are:

Speed impedance FV			
Speed (km/h)	**Risk of fatality**	**Risk of severe injured**	**Adopted index**
20	1%	5 %	**0,05**
30	2 %	10 %	**0,1**
40	5 %	25 %	**0,25**
50	10 %	50 %	**0,50**
60	50 %	65 %	**0,65**
70	70 %	77 %	**0,77**
80	90 %	92 %	**0,92**
90	95 %	97 %	**0,97**
100	99 %	99 %	**0,99**
120	100 %	100 %	**1.00**

Table 21 - Speed impedance

Traffic volume impedance

According to the literature previously mentioned, traffic conditions are one of the most important variables when it comes to traffic safety perception. Therefore, we have decided to weight the importance of the traffic conditions (Vehicle speed, Total ADT and heavy vehicles) by using a MCA methodology.

Experts were asked to complete a test in which they had to indicate which of the three variables considered for traffic conditions were the most important ones, and the results are as follows:

1st Element Most Dangerous					
		Frequency	Percentage	Percentage valid	Percentage accumulate
Valid	Amount of heavy vehicles	3	5,5	5,5	5,5
	Total ADT	10	18,2	18,2	23,6
	Vehicle speed	42	76,4	76,4	100
	Total	55	100	100	

Table 22 – Traffic Conditions (Most dangerous)

2nd Element Most Dangerous					
		Frequency	Percentage	Percentage valid	Percentage accumulate
Valid	Amount of heavy vehicles	11	20	20	20
	Total ADT	35	63,6	63,6	83,6
	Vehicle speed	9	16,4	16,4	100
	Total	55	100	100	

Table 23 - Traffic Conditions Frequencies (Second most dangerous)

Applying MCA analysis in the same way as before, the weights are:

TRAFFIC CONDITIONS					
	1º	2º	3º	Total	Weight
Heavy ADT	9	121	1681	1950	21%
ADT	100	1225	100	2850	33%
Speed	1764	81	16	5470	46%
			SUM	10270	100%

Table 24 – Score and weigh for traffic conditions

The weights are:

- D = 0,46
- E = 0,33
- F = 0,21

Now we have to range the amount of traffic volume from 0 (Lowest impedance) to 1 (Highest impedance). The original impedance methodology used a Logarithmic Function, but we suggest to apply a Square Root Function. The reason is because using a logarithmic function, lower values of AADT are given considerable high impedance compare with higher values of AADT, while the square root range better the different values of AADT.

Safety-in-numbers refers to the tendency for the accident rate of a certain group of road users to go down as the group becomes more numerous. The existence of such an effect is best determined by developing accident prediction models of the form (Elvik et al., 2009):

$$Expected\ nº\ of\ accidents\ =\ e^{\beta_0} \times (PED)^{\beta_1} \times (MV)^{\beta_2} \times e^{\sum \beta_1 X_i}$$

PED (alternatively CYC) denotes pedestrian (or cyclist) volume, MV denotes motor vehicle volume (usually in terms of AADT = Annual Average Daily Traffic), e is the exponential function, Xi (i = 1 to n) represents risk factors influencing safety, e.g. the mean speed of traffic, the number of travel lanes, the number of legs in junctions, etc. and βi are coefficients which are normally estimated by means of negative binomial regression. If the coefficients referring to traffic volume (β1 and β2) are less than one, this indicates the presence of a safety-in-numbers effect.

Roughly speaking all coefficients are about 0.5. An exponent of 0.5 is the same as a square root transformation of a variable. This implies that a doubling of traffic volume will be associated with a 41 % increase in the expected number of accidents, since the square root of 2 equals about 1.41:

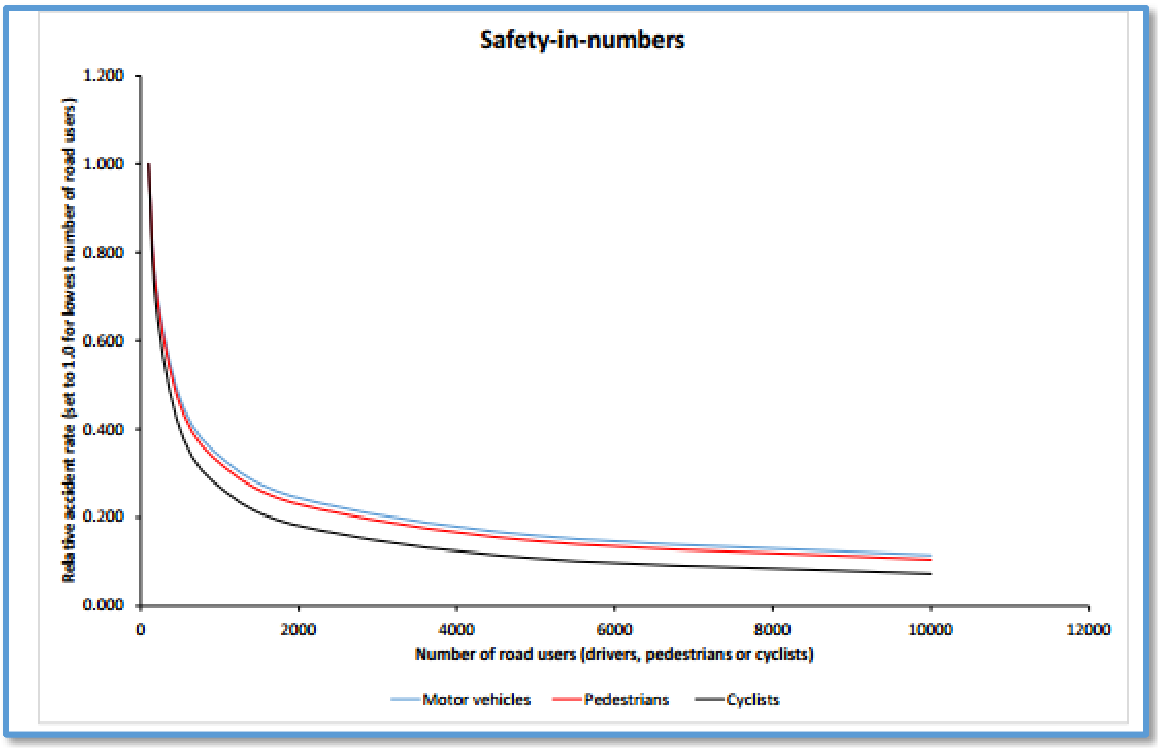


Figure 35 - Safety in numbers model

Not only the vehicle traffic is important but also it is pedestrian volumes. In one study conducted in 2005 (Jonsson, 2005) three different sets of models were developed, one with just road data and the function class of the street, another which included data on land use along the street, and one more including pedestrians/bicyclists volume data. The models with just road data explained 37% of the variation, while the models using pedestrian/bicyclist volumes could explain 71-81% of the variation. If pedestrian and bicyclist volumes are not available, then models including land use is a 'second best' solution explaining 54-55% of the variation. Methodologies for pedestrian volume counts are also explained.

We will however not include pedestrian volume (It will be assumed to be constant) on streets in order to simplify the model, but it could be an improvement for further research to ask respondents whether the presence of other pedestrian along the street changes their feeling of security.

With this background, the values of F_{AADT} are:

Traffic Impedance FAADT									
ADT	**Root function**	**Log Function**	**Root coefficient**	**Log Coefficient**	**ADT Heavy**	**Root function**	**Log Function**	**Root coefficient**	**Log Coefficient**
1	1,0	0,0	**0,01**	0,00	**1**	1,0	0,00	**0,01**	0,00
10	3,2	1,0	**0,02**	0,23	**5**	2,2	0,70	**0,03**	0,18
20	4,5	1,3	**0,03**	0,30	**10**	3,2	1,00	**0,04**	0,26
50	7,1	1,7	**0,04**	0,39	**15**	3,9	1,18	**0,04**	0,30
100	10,0	2,0	**0,06**	0,45	**20**	4,5	1,30	**0,05**	0,34
150	12,2	2,2	**0,08**	0,49	**40**	6,3	1,60	**0,07**	0,41
200	14,1	2,3	**0,09**	0,52	**50**	7,1	1,70	**0,08**	0,44
300	17,3	2,5	**0,11**	0,56	**75**	8,7	1,88	**0,10**	0,48
400	20,0	2,6	**0,13**	0,59	**100**	10,0	2,00	**0,12**	0,52
500	22,4	2,7	**0,14**	0,61	**150**	12,2	2,18	**0,14**	0,56
750	27,4	2,9	**0,17**	0,65	**200**	14,1	2,30	**0,16**	0,59
1000	31,6	3,0	**0,20**	0,68	**300**	17,3	2,48	**0,20**	0,64
1500	38,7	3,2	**0,24**	0,72	**400**	20,0	2,60	**0,23**	0,67
2000	44,7	3,3	**0,28**	0,75	**500**	22,4	2,70	**0,26**	0,70
3000	54,8	3,5	**0,34**	0,79	**750**	27,4	2,88	**0,32**	0,74
5000	70,7	3,7	**0,44**	0,84	**1000**	31,6	3,00	**0,37**	0,77
7500	86,6	3,9	**0,54**	0,88	**1250**	35,4	3,10	**0,41**	0,80
10000	100,0	4,0	**0,63**	0,91	**1500**	38,7	3,18	**0,45**	0,82
12500	111,8	4,1	**0,70**	0,93	**2500**	50,0	3,40	**0,58**	0,88
15000	122,5	4,2	**0,77**	0,95	**3000**	54,8	3,48	**0,63**	0,90
20000	141,4	4,3	**0,88**	0,98	**4000**	63,2	3,60	**0,73**	0,93
22500	150,0	4,4	**0,94**	0,99	**5000**	70,7	3,70	**0,82**	0,95
25000	158,1	4,4	**0,99**	1,00	**7500**	86,6	3,88	**1,00**	1,00

Table 25 - Traffic Impedance

2.5- Pedestrian crossing Impedance Index

$$I_C = \frac{L}{V_w} \times S = \frac{L}{V_w} \times (C \cdot F_C + B \cdot F_T)$$

Where:

- I_C = Feeling of Insecurity Impedance Index for a given pedestrian crossing
- L = Length in meters
- V_w = Walking speed
- C, B = Weight coefficients
- F_C = Pedestrian crossing infrastructure impedance
- F_T = Traffic conditions impedance

Now we are going to explain each of the main factors in detail.

2.5.1- Weigh coefficients

The original impedance methodology equally weighed the infrastructures where pedestrians cross the street, and the traffic conditions where vehicles circulate. However, it could be that traffic conditions or the infrastructure are perceived differently by road users, and thus, they have a preference regarding where to cross.

Therefore, collecting information with surveys will give us the expert's preference. Under the MCA and AHP methodology explained before, these coefficients are calculated as follows:

1st element more dangerous					
		Frequency	**Percentage**	**Valid**	**Accumulated**
Valid	**Traffic volume and vehicle speed**	16	29,1	29,1	29,1
	The streets	9	16,4	16,4	45,5
	The pedestrian crossings	30	54,5	54,5	100
	Total	55	100	100	

Table 26 - Crossing weight 1st

2nd element more dangerous					
		Frequency	Percentage	Valid	Accumulated
Valid	Traffic volume and vehicle speed	19	34,5	34,5	34,5
	The streets	17	30,9	30,9	65,5
	The pedestrian crossings	19	34,5	34,5	100
	Total	55	100	100	

Table 27 - Crossing weight 2nd

	1º	2º	3º	TOTAL	Weight
TRAFFIC	256	361	400	1890	39%
CROSSINGS	900	361	36	3458	61%
			SUM	5348	100%

Table 28 - Weigh coefficients for pedestrian crossings

Therefore the values for the weight coefficients are:

- C = 0,61
- B = 0,39

2.5.2- *Pedestrian crossing infrastructure impedance F_C*

This factor refers to the quality of the infrastructure for crossing purposes. Raised crosswalks, marked, are given the best scores while pedestrian crossings without signals are given lower scores.

The rating of FC is from 0 (No impedance) to 1 (High impedance). In order to give a crosswalk a score, the existence of markings, pedestrian phasing, lighting and other factors have been taken into account. To better illustrate this, here we present two real examples:

Figure 36 – Left: Crossing Impedance F_C = 1, Right: Crossing Impedance F_C = 0

In order *to* determine the score between 0 and 1, a MCA methodology has been applied. Surveys provided us with information about road users preferences.

Not all the factors will be used for all the crosswalks. First, we will check which features should be included for each crosswalk according to the *Chapter II: Streets and Pedestrian Crossings – Definition and Classification*. This means that we are going to have different weighted features coefficients for each kind of pedestrian crossing.

In Appendix 4B – Crossing Impedance Methodology, material is provided with which to calculate the impedance for each kind of street.

Under the MCA methodology previously explained, the following table shows one of the results obtained as an example:

Crossing Coefficients						
	Marking	**Signals**	**Traffic Lights**	**Speed measures**	**Refugee/Island**	**Lighting**
Collector link, or Local link with > 8.000 ADT and Speed Limit 40 – 50 km/h (Large crossings)						
DAY	10%	14%	27%	29%	19%	-
NIGHT	7%	11%	21%	22%	15%	24%
Collector link, or Local link with > 8.000 ADT and Speed Limit 40 – 50 km/h						
DAY	13%	18%	34%	36%	-	-
NIGHT	9%	13%	24%	26%	-	28%
Local link with < 8.000 ADT and Speed Limit 30 – 40 km/h						
DAY	19%	27%	-	54%	-	-
NIGHT	12%	17%	-	34%	-	36%
Residential link with Speed Limit 30 km/h						
DAY	-	-	-	100%	-	-
NIGHT	-	-	-	50%	-	50%

Table 29 – Crossing Example C1 Table

The value of F_C for each polyline representing a pedestrian crossing is calculated as follows:

$$F_C = \sum f_C = \sum C_1 C_2$$

Where:

- C_1 = Feature coefficient. It weighs the different features crossing a street according to the expert's preference.
- C_2 = Condition feature. It gives a score according to the feature's condition.

2.5.3- Traffic conditions impedance

Already explained in *b) Link impedance index.*

3- METHODOLOGIES COMPARISON

To conclude with this chapter and in order to summarize the differences between the original methodology and the improvements we have done, we can build the following table:

Element	FHWA Impedance methodology	Improved Impedance Methodology
Measurement	Hazardousness	**Safe perception**
Vehicle speed considered	Speed Limit	**Actual Speed (Assumed)**
Rating scale	1 – 5 usually, sometimes higher than 5 (Inconsistent)	**0 – 1 (Consistent)**
Traffic Volume rating function	Logarithmic	**Square root**
Links features considered	YES	YES
Pedestrian crossings features considered	YES	YES
One/Two ways	YES	YES
Pedestrian volume	NO	NOT YET
Heavy ADT considered	YES	YES
Total ADT considered	NO	YES
Pedestrian crossings at different level considered	NO	YES
Lighting conditions considered	NO	YES
Units comparison	NO	YES
Factors weighed	NO	YES
Type of road considered	NO	YES
Shared traffic roads considered	NO	YES
Route often used by children	NO	YES

Table 30 - Comparison table

CHAPTER V:

The Study Case of Singsaker School

V) THE STUDY CASE OF SINGSAKER SCHOOL

1- THE SCHOOL WITHIN THE URBAN FORM

1.1- *Introduction and scope*

In order to validate the results of the proposed methodology, a real-world case study has been developed. This study focusses on a single school because of the limited period for completion of this Master's project. The school in this study case is Singsaker Primary School, in the city of Trondheim.

Singsaker Elementary School is located in Singsaker, just 1.5 km from central Trondheim. The school was reopened as a primary school in autumn 1995. Every year, the school has between 350 and 400 pupils and about 60 employees.

1.2- *Study area characteristics*

The neighborhood of Singsaker is a district close to the city center of Trondheim. This city is the third biggest city in Norway with a total population of 184,960 (2015) occupying an area of 342,27 km^2.

The Singsaker neighborhood functions mainly as a residential area with the exception of the Norwegian University of Technology and Science (NTNU), which is situated here. The district is bordered by one major road called Elgesetergate, which reaches the city center. An overview of the building distribution can be found in *Map Appendix 5F – Building Distribution*

A collector street called Eidsvolls Gate crosses from the west to the east of the district, connecting Elgesetergate with Festningsgata. Two important local streets called Hogskleringen and Lillegardsbakken cross the district from the south to the north. An overview of the school location and street hierarchy can be found in *Map Appendix 5G – Street Hierarchy*.

As mentioned in *Chapter II – Streets and Pedestrian Crossings – Definition and Classification*, schools should be placed in streets with good accessibility and should avoid complex intersections or busy roads.

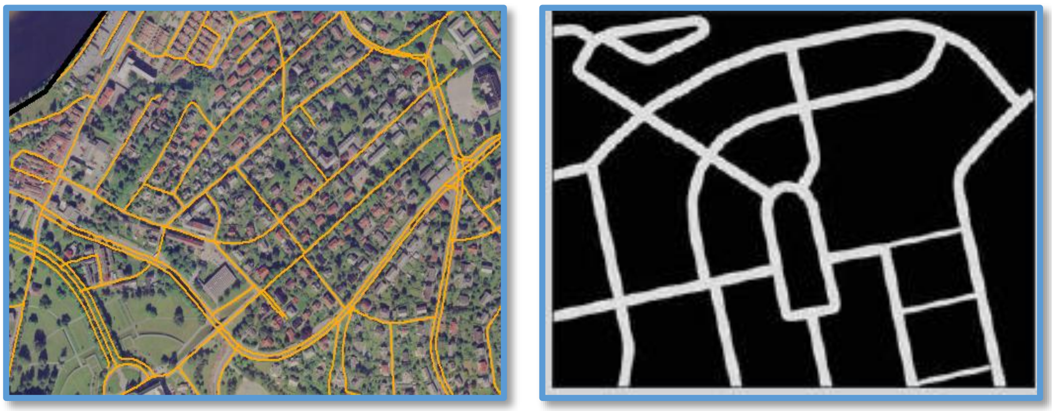


Figure 37 - Urban layout of Singsaker district

The layout of the district tends to be curvilinear and therefore accessibility is guaranteed to a great extent. Permeability is high for all road users so it could be classified as an “Open Network”. Moreover, all the streets and roads are classified as “Inner Roads”. However, there is an important road which, as mentioned above, crosses the entire neighborhood and divides the school boundary into two parts. Clearly, children face a barrier and are forced to cross such a street. A better illustration of the problem can be found in the previous map which shows the school, the collector street and complex intersections.

1.3- __School Selection__

The school selection process will help us to classify all the primary schools within the urban form of the city of Trondheim prior to our analysis. The starting point is to establish a common criteria for all schools, and that will be accidents in the streets.

We will make use of the Safety Cost Parameter in order to classify all the primary schools. The parameter will be calculated per school walkable area (radius 2km with the school as the center point) and for a period of 10 years (2007 – 2017) including accidents involving both pedestrians and cyclists.

The process will be as follows:

- Dataset including primary schools and accidents involving pedestrian and cyclists.
- Draw a 2 km buffer from each school
- Calculate the Safety Cost parameter for each school within its buffer.

The Safety Cost parameter can be define as follows (Elvik et al., 2009):

$$\boldsymbol{SK} = \frac{(49'22 \times DR + 37'35 \times MAS + 13'26 \times AS + 1 \times LS) \times 614.000}{Km \times Years}$$

We will calculate for each school area, so we will instead use:

$$\boldsymbol{SK}(\boldsymbol{per\ school}) = \frac{(49'22 \times DR + 37'35 \times MAS + 13'26 \times AS + 1 \times LS) \times 614.000}{Years}$$

Where

- DR = Fatal injuries
- MAS = Seriously Injured
- AS = Severely Injured
- LS = Slightly Injured

A certain amount of data is available that contains information regarding vehicle traffic. The following datasets are downloaded through the NVBD API for ArcMap developed by the NRPA, and contain several different types of data. The information available regarding accidents to be downloaded is:

- Traffikulykke: Information about accident location, weather conditions, type of accident, and the level of injuries, primarily applying to accidents with injuries. Here we show the dataset from the year 2017 and classified by the level of injury.
- Ulykkesinvolvert Enhet: People involved in the traffic accident (Inside vehicles).
- Ulykkesinvolvert Person: Units involved in the accident. A pedestrian is also regarded as one unit.
- Ulykkespunkt: A point on the road that is particularly susceptible to accidents. A stretch of 100 meters which has 4 or more accidents within a period of 5 years.

- Ulykkesstekning: A stretch of road that is particularly prone to accidents. A stretch of 1000 meters that has 10 or more accidents within a period of 5 years.
- Ulykkesstekning Egendefinert: Information about accident location, weather conditions, the level of injuries mm. Applies primarily to accidents with injuries.

In order to classify schools in terms of the Safety Cost parameter, we need the dataset which contains the severity of injury. Therefore, the dataset that will provide us with the type of accident and the level of injury is “Traffikulykke”. Selecting all the accidents from the period 2007 – 2017 involving either pedestrians or cyclists we have all the data needed to calculate the SK parameter for each school. The results can be checked in *Map Set Appendix 5A – School Selection*.

In conclusion, the school to be studied will be the first school ranked based on this criteria. Therefore, Singsaker School is chosen for this study case.

The following table shows a summarize of the results:

School Ranking	School Name	SK (Million Kr per school area)
1º	**Singsaker**	**64,197**
2º	Berg	**60,745**
3º	Kalvsskinnet	**58,228**
4º	Bispehaughen	**52,652**
5º	Ila	**45,462**
6º	Asveien	**41,148**
7º	Nardo	**37,267**
8º	Nidarvoll	**35,700**
9º	Eberg	**30,748**
10º	Steindal	**27,280**
11º	Strindheim	**23,602**
12º	Asvang	**18,353**
13º	Nyborg	**17,800**
14º	Breidablikk	**17,325**
15º	Byasen	**16,922**
16º	Saupstad	**15,865**
17º	Harstad	**14,357**
18º	Hallset	**13,989**
19º	Stabbursmoen	**13,484**
20º	Kattem	**13,324**
21º	Rosten	**12,080**
22º	Kolstad	**11,484**

School Ranking	School Name	SK (Million Kr per school area)
23º	Okstad	**10,029**
24º	Romuslia	**9,880**
25º	Brundalen	**9,680**
26º	Lade	**9,672**
27º	Dalgard	**8,537**
28º	Flatasen	**8,535**
29º	Charlottenlund	**7,675**
30º	Utleira	**6,984**
31º	Stavset	**6,281**
32º	Rotvoll	**5,985**
33º	Tonstad	**4,853**
34º	Sjetne	**3,916**
35º	Nypvang	**3,268**
36º	Ranheim	**1,612**
37º	Ranheim	**1,367**
38º	Vanheim	**0,937**
39º	Vikasen	**0,430**
40º	Solbakken	**0,123**

Table 31 - Safety Cost

1.4- Building the Network

To avoid repetition, please consult *Chapter III – Building a Pedestrian Street Network*. In this section, we will simply comment on how the network, once built, was prepared for use. We assume here that the network contains all the polylines that constitute a network for pedestrians and it includes links along which they walk, crossings where they are able to cross the street, and other minor paths and shared used streets.

Therefore, with the street network once built, it is time to follow *Chapter IV – Feeling of Insecurity Impedance Methodology* to calculate for each link and crossing the correspondent impedance. To avoid repentance, please refer to Chapter IV.

1.5- Research Questions

We are now going to present the research questions to be answered:

- *What is the accessibility of the school?*
- *What are the shortest routes?*
- *What are the routes with the lowest feeling of insecurity?*
- *What are the preferred routes of children? How different are they compared with the shortest and the most secure routes?*
- *Where could we improve the feeling of security on those preferred routes?*

2- WHAT IS THE ACCESSIBILITY OF THE SCHOOL?

2.1- Walking Time

In the classic approach to accessibility, the attribute used as an impedance cost is distance or walking time. When assessing the accessibility of an area or a region to a certain location the concept of "*Service Area*" is introduced. It can be defined as follows:

"*A network service area is a region that encompasses all accessible streets (that is, streets that are within a specified impedance). For instance, the 5-minute service area for a point on a network includes all the streets that can be reached within five minutes from that point. Service areas created by Network Analyst also help to evaluate accessibility. Concentric service areas show how accessibility varies with impedance. Once service areas are created, you can use them to identify how much land, how many people, or how much of anything else is within the neighborhood or region*" (ESRI, 2017)

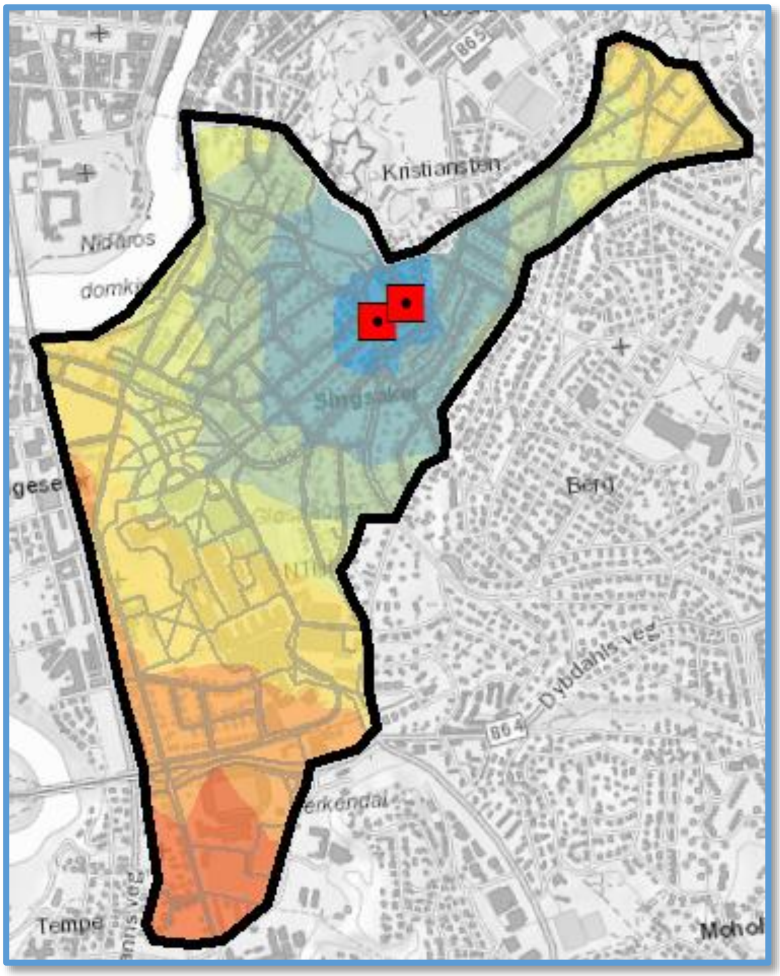


Figure 38 - Accessibility in Walking Time

The maximum walking distance should be 2 km from the school to the children's houses. (Brown et al., 2015) That is a maximum walking time of 25 minutes.

The map can be checked with better resolution in *Map Set Appendix 5B – Accessibility (Walking Time)***.**

Here we present a table with all the residential houses and their relation to walking time to school:

Walking Time to School				
Walking Time	**Nº of residential buildings**	**% out of the total**	**Area (Ha)**	**% Area**
< 5 min	35	3%	6,74	3%
< 7,5 min	275	20%	26,92	12%
< 10 min	339	25%	28,98	12%
< 15 min	299	22%	31,06	13%
< 20 min	225	17%	51,32	22%
< 25 min	120	9%	37,34	16%
> 25 min	58	4%	50,70	22 %

Table 32 – Walking time to school

What we can observe in this table is that most residential houses are under the 10 minutes service area (25%) and under the 15 minutes service area (22%), which taking into account the 7,5 and 5 minutes gives a total of 70% of residential houses under a 15 minutes walk. We can conclude saying that most of the children would be under the desirable maximum walking distance, which is 25 minutes.

The street network was classified as an open network and therefore there are no restraints or barriers regarding walking time. This is to say, with regards to walking time there is a limited range of improvement and therefore houses within a walking time of more than 25 minutes might be relocated to a closer school in order to avoid having children walk further than this.

As the security impedance attribute is directly proportional to the walking time, it is clear that the further a child has to walk to school, the more impedance they will face. Therefore, only by improving the physical features of the street network will the insecurity impedance for a child be reduced.

Once we have studied the classical definition for accessibility it is time to assess the new approach that this master's thesis brings in terms of accessibility, and this is changing "walking distance" by "feeling of insecurity".

2.2- <u>Feeling of Insecurity</u>

This is one of the new ideas that this Master´s thesis presents when assessing the insecurity that people perceive on streets and crossings. The difference between this and the former definition of accessibility is that in this case we use a new variable, and walking time impedance cost is replaced by Insecurity Impedance cost.

As we can see in the following easily understood example, the route choice is different and so this will be the service area.

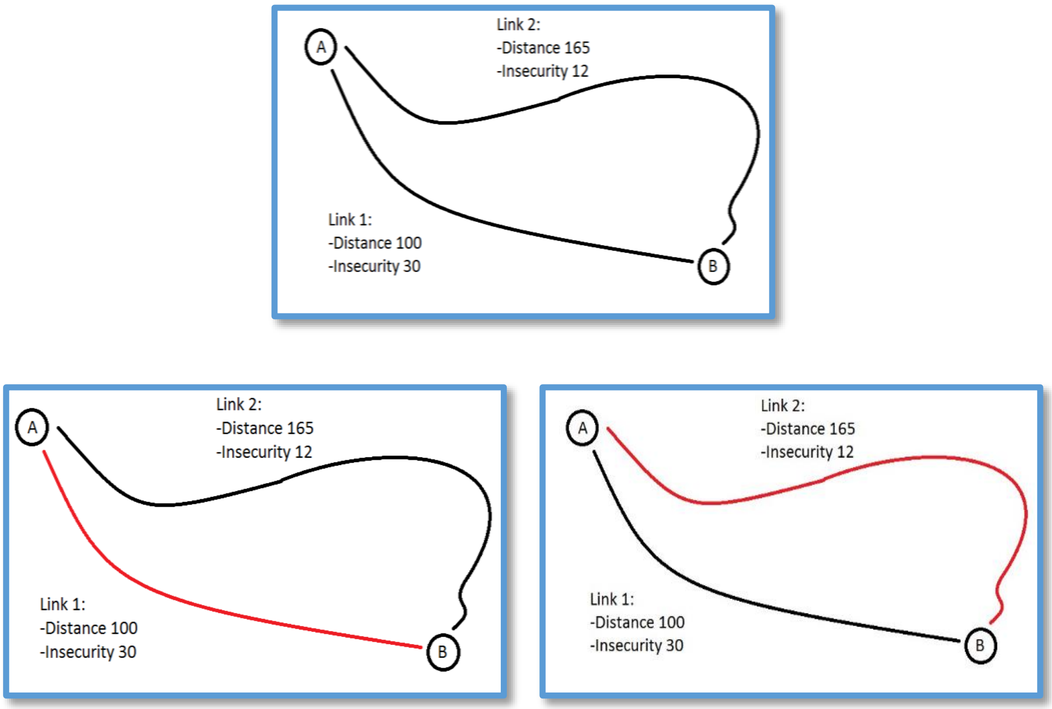


Figure 39 Left: Shortest Route, Right: Most secure route

Therefore, by recalculating the service areas what we find are areas where children face the same insecurity on the streets.

The ideal map using this criteria will be a map with "0 seconds" of insecurity impedance; that is, a region or neighborhood where - hypothetically - people feel completely secure on both streets and crossings and there is little or no motorized traffic on the network. A few cities around the world might enjoy this ideal situation (for example, the old town of Venice, where motorized traffic is prohibited).

On the other hand, in a region or a neighborhood with no street and crossing facilities for pedestrians, where there is no clear speed limit and all the streets share every type of traffic, we would have maximum insecurity and Insecure Impedance is equal to Walking Time. This second hypothetical situation states that children are always exposed to motorized traffic and there is the need to maintain continual vigilance on their way to school. A situation in between these two hypothetical solutions would be realistic, as in this school study case.

This type of map can help us to identify "corridors" where pedestrians can easily travel whilst facing little or no insecurity. They are also a useful tool to identify barriers with a high insecurity cost that should be assessed from a traffic safety point of view to identify hazardous issues. And finally they can be used as a tool to shape people's perception of the security of the street network before and after implementing improvements to the network.

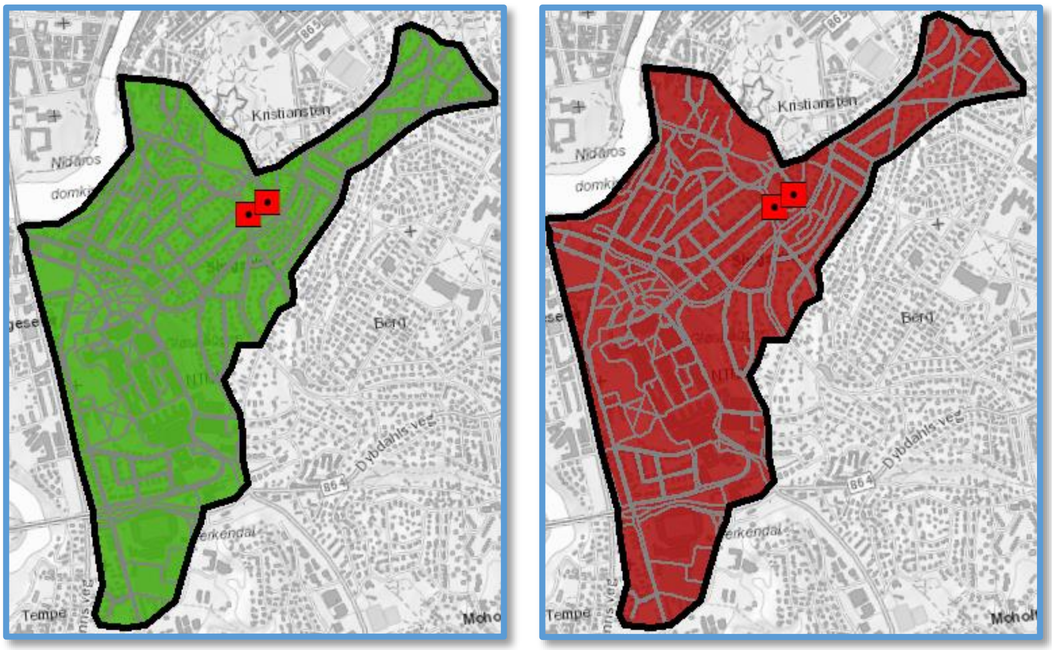


Figure 40 – Hypothetical cases, Left: No feeling of insecurity, Right: Maximum feeling of insecurity

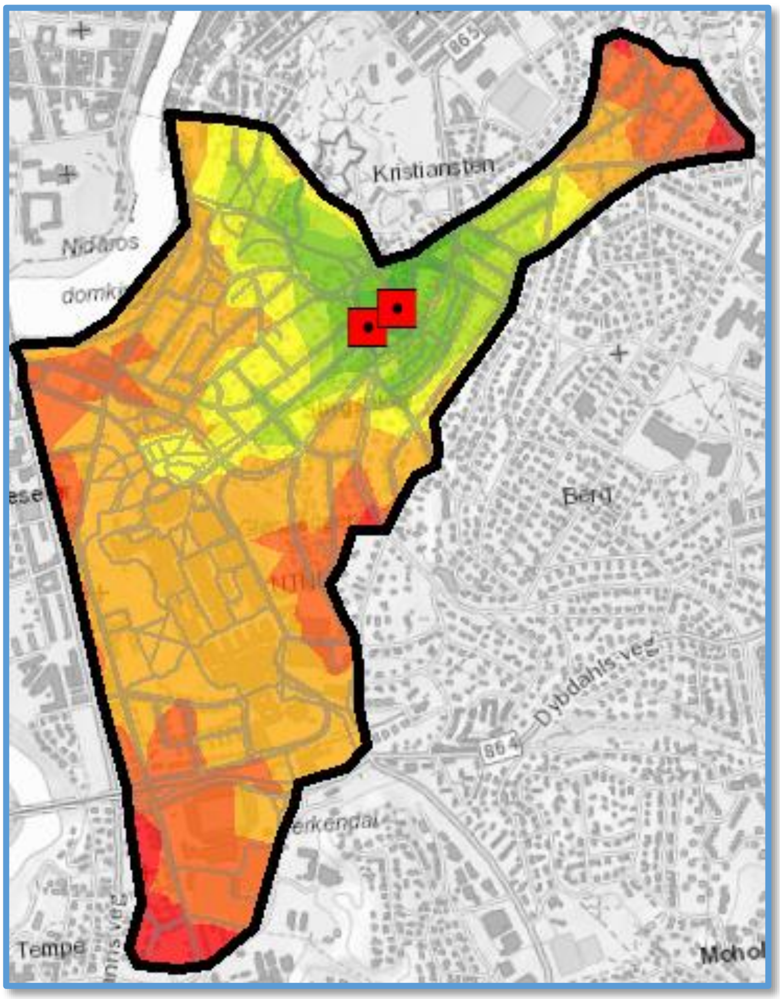


Figure 41 - Singsaker School "Feeling of Insecurity", Green: Low, Red: High

A higher resolution map can be found in *Map Set Appendix 5C – Accessibility (Feeling of insecurity).*

We found that nearly 75% of all the residential houses are under 100 seconds of insecurity (1 minute and 30 seconds) and only 3% of the houses are under 20 seconds of insecurity.

These kind of findings can help to assess the accessibility in terms on insecurity in the streets due to traffic vehicle issues. One could expect that implementing measures in order to improve the infrastructure quality of the street network, the service areas under the impedance attribute "feeling of insecurity", occupy a larger extension and therefore the accessibility is improved.

Here we present a table with all the residential houses and their relation to walking time to school:

Insecure Time to School				
Insecure Time	**Nº of residential buildings**	**% out of the total**	**Area**	**% Area**
< 20 sec	35	3%	6,74	3%
< 50 sec	279	21%	24,34	11%
< 75 sec	353	26%	29,91	13%
< 100 sec	334	25%	65,32	28%
< 150 sec	317	23%	76,09	33%
> 150 sec	33	2%	28,78	12%

Table 33 - Feeling of Insecurity to School

.

3- WHAT ARE THE SHORTEST AND THE MOST SECURE ROUTES?

3.1- Shortest routes

This analysis will help us to identify corridors where children walk to school when choosing the shortest route. In order to assist the software in solving the routes, two main entrances around the school have been included instead of using the school building as the only facility to be found on the network. This is actually a better representation when a child goes to school, as they look for the closest main entrance.

Drawing one route from each residential house to the school's entrance, we obtain a map with all the shortest routes from each house. Clearly, they are going to merge at some point and therefore by using the tool Linear Density we can draw a new map that shows the frequency of time a street is walked. A higher resolution map can be found in *Map Set Appendix 5D – Shortest Corridors***.**

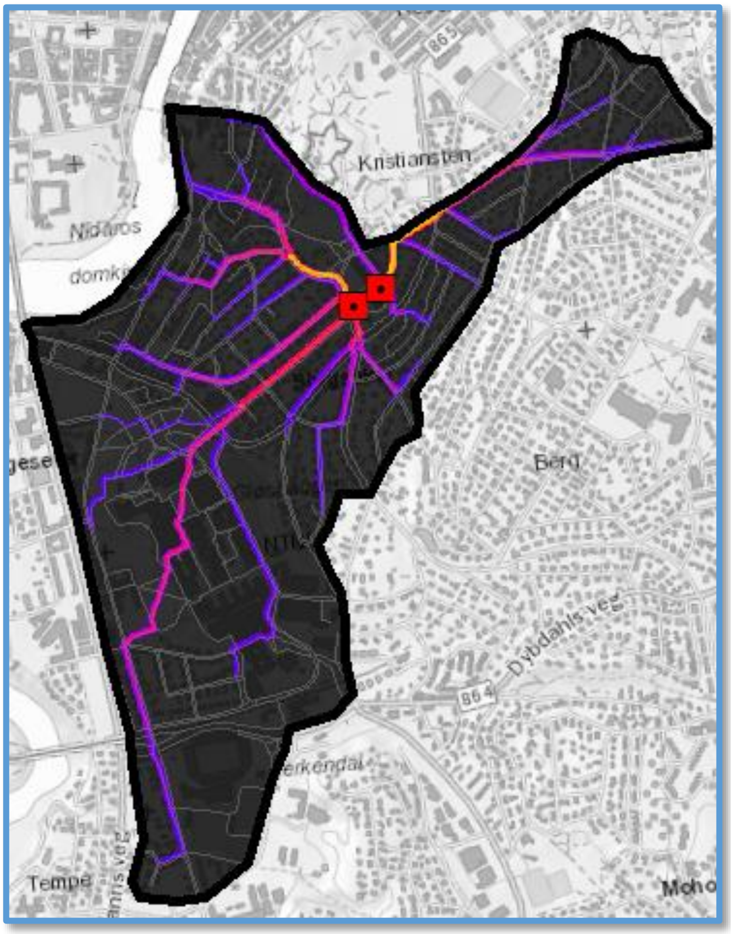


Figure 42 - Shortest Routes

It should be mentioned that it was not possible to obtain the distance in 3D due to the low resolution of the 3D model of the terrain (50m cell size). With this resolution, the 3D model would be less accurate than the 2D distance.

Therefore, the 2D topographic distance has been used as an approximation of the real walking distance. For further research, it would be more accurate to work with a 3D topographic distance.

Now we will consider the most notable short corridors found by using the walking time as the impedance variable.

By analyzing the results, we can identify the following shortest corridors:

3.1.1- <u>High frequency</u>

Indicated in yellow in *Map Set Appendix 5D – Shortest Corridors*, we have two corridors with high frequency.

- Lillegårdsbakken – Jonsvannsveien (*Figure 8)*

This first corridor approaches from the western part of the district via the local street of Lillegårdsbakken, then takes Jonsvannsveien to reach the southern entrance of Singsaker School. This corridor appears to serve all the residential houses close to Nidelva River on the side of Øvre Bakklandet and also some of the houses close to the Old Bridge (Gamle Bybro).

The following table shows the main characteristics:

Corridor Characteristics	
ADT	1.500 – 2.500
ADT Heavy	30 %
Speed limit	30 – 40 km/h
Street facilities	Mostly with normal sidewalks
Crossing facilities	Mostly marked and signalized crosswalks

Table 34

- Tyholtveien - Schmidts Gate *(Figure 9)*

This second corridor comes from the north side of the district, crossing the collector street of Eidsvolls Gate. Almost all the routes from the residential houses within the north part will eventually merge with this corridor and finally arrive at the northern entrance of Singsaker School.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	500 – 2.500
ADT Heavy	< 5 %
Speed limit	30 – 40 km/h
Street facilities	Mostly with normal sidewalks, some are shared use
Crossing facilities	Marked, signalized and the most important ones with traffic lights

Table 35

3.1.2- Medium frequency:

Indicated in pink in *Map Set Appendix 5D – Shortest Corridors,* we can distinguish three main corridors

- Eidsvolls Gate - Bergsbakken – Jonsvannsveien. *(Figure 10)*

This corridor originates with three streets merging at the main intersection in Jonsvannsveien, gathering routes from the residential houses in the south-central part of the district. This intersection is regulated by traffic lights and also has refuge islands to facilitate crossing the street.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	2.500 – 10.000
ADT Heavy	< 5 %
Speed limit	40 – 50 km/h, some parts with 30 km/h
Street facilities	Mostly with normal sidewalks, and many with buffers
Crossing facilities	Marked, signalized and the most important ones with traffic lights

Table 36

- Øvre Alle *(Figure 10)*

This is the longest of the short corridors. It crosses the collector street of Jonsvannsveien, proceeding over the bridge and through the University area, giving access to all the houses situated in the south and south-west of the district.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	1.500 – 2.500
ADT Heavy	< 5 %
Speed limit	30 km/h
Street facilities	Poor sidewalks on residential streets, and many are shared use.
Crossing facilities	Mostly not marked or signalized (not necessary)

Table 37

- Singsakerbakken - Nedre Alle *(Figure 12)*

The second longest short corridor concentrates routes from residential houses situated in the west of the district and close to the river.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	< 500
ADT Heavy	< 5 %
Speed limit	30 Km/h
Street facilities	Poor sidewalks, many are shared use.
Crossing facilities	Mostly not marked or signalized (not necessary)

Table 38

- Kristianstensbakken *(Figure 13)*

This corridor goes beneath Kristiansten Festning, merging routes from the most northerly part of the district.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	1.500 – 2.500
ADT Heavy	< 5 %
Speed limit	30 km/h
Street facilities	Mostly without sidewalk
Crossing facilities	Mostly not marked or signalized

Table 39

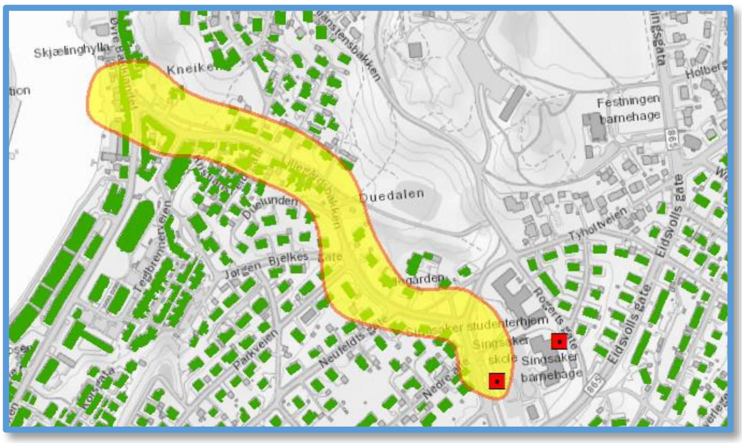


Figure 43 - Lillegårdsbakken – Jonsvannsveien

Figure 44 - Tyholtveien - Schmidts Gate

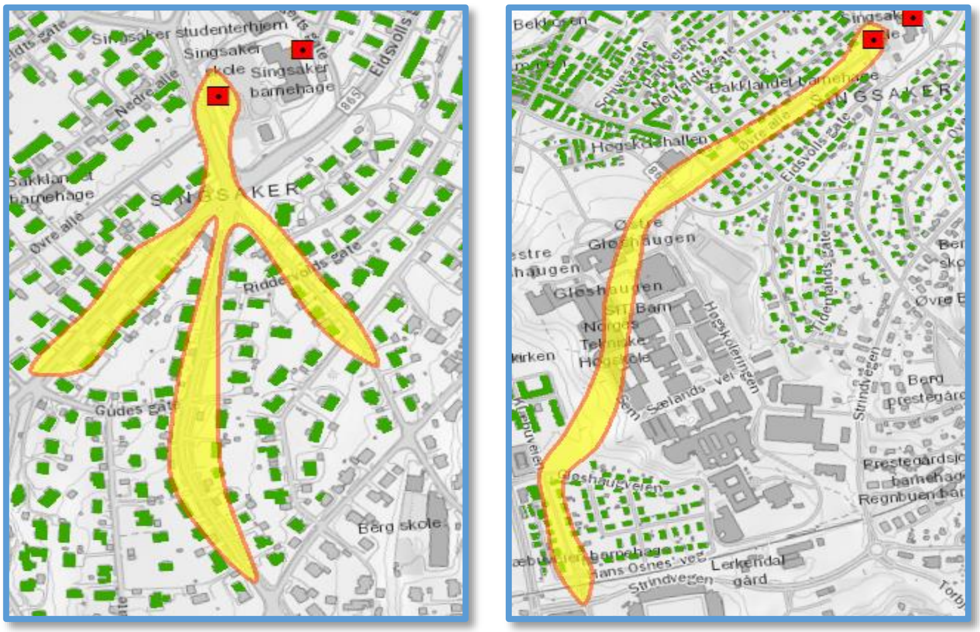


Figure 45 – Left: Eidsvolls Gate - Bergsbakken – Jonsvannsveien, Right: Øvre Alle

Figure 46 - Singsakerbakken - Nedre Alle

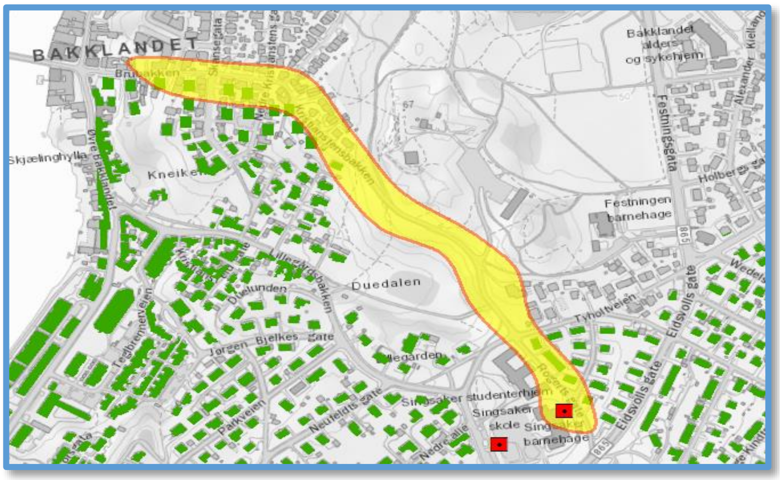


Figure 47 - Kristianstensbakken

3.2- Routes with the lowest feeling of insecurity

By using the insecurity impedance cost to indicate a route from each residential house to the school, we obtain a map with all of the most secure routes from each house. Clearly, they are going to merge as well at some point and therefore by using the tool Linear Density again, we can draw a new map that shows the frequency with which a street is walked. A higher resolution map is available in *Map Set Appendix 5E – Corridors with the lowest feeling of insecurity.*

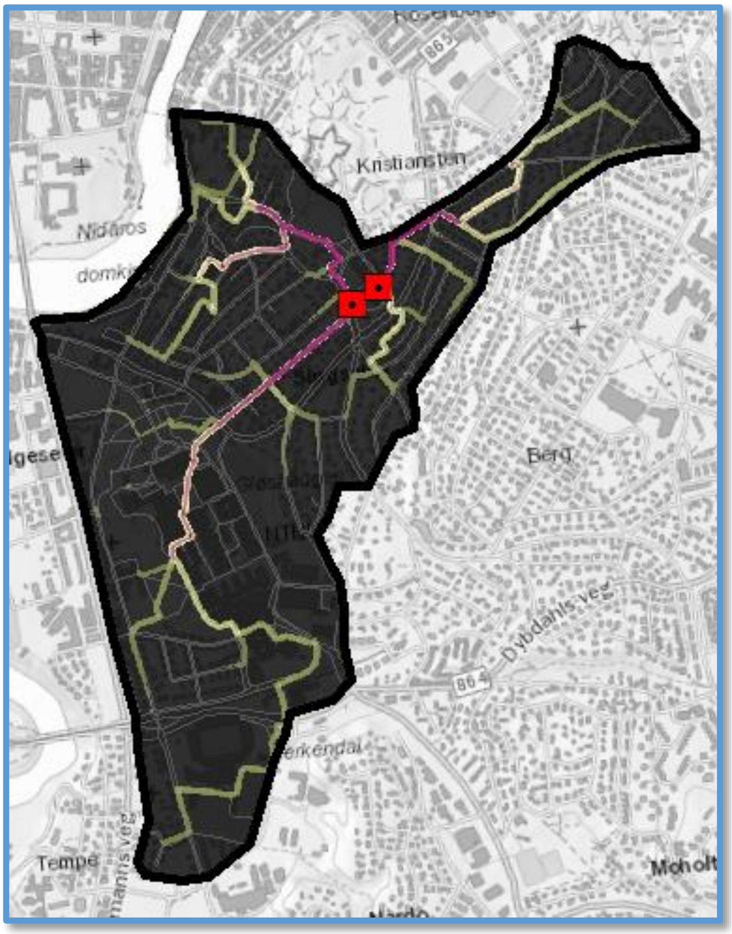


Figure 48 – Lowest Insecurity Corridors

It should be mentioned again that the feeling of insecurity is a subjective attribute and therefore it can produce many different results depending on the model adopted and the variables considered. In this case, our model is built to score positively those streets with open sidewalks and buffers, with low speed levels and motorized traffic and giving the best scores to paths or streets with shared use.

However, it is a useful tool for modelling pedestrian behavior in terms of insecurity impedance as this analysis could give some idea of where pedestrians are experiencing high levels of cost impedance.

Now we are going to consider the most notably secure corridors identified by using the insecurity time as the impedance variable.

Analyzing the results we can identify the following most secure corridors:

3.2.1- High Frequency:

- Schmidts – Tyholtveien:

This corridor, relatively similar to its equivalent in walking time, approaches from the north side of the district and crosses the collector street of Eidsvolls gate. Almost all the routes from the residential houses within the northern part will eventually merge with this corridor and finally arrive at the northern entrance of Singsaker School. A number of variations can be identified, for example going through Falsens Gate to avoid motorized traffic.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	500 – 2.500
ADT Heavy	< 5 %
Speed limit	30 – 40 km/h
Street facilities	Mostly with normal sidewalks, some are shared use
Crossing facilities	Marked, signalized and the most important ones with traffic lights

Table 40

- Lillegårdsbakken - Jonsvannsveien

This corridor, also similar to its equivalent in walking time, arrives from the west through Lillegårdsbakken and takes Jonsvannsveien to the southern entrance of Singsaker. This corridor appears to serve all of the houses close to the river and some of the houses close to the Old Bridge. The main difference appears when taking paths through open fields instead of Lillegårdsbakken at some stages.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	1.500 – 2.500
ADT Heavy	30 %
Speed limit	30 – 40 km/h
Street facilities	Mostly with normal sidewalks, and some are paths through open field
Crossing facilities	Mostly marked and signalized crosswalks

Table 41

- Øvre Alle

This is the longest, most secure corridor of all, and it is also similar to its equivalent in walking time. It crosses the collector street of Jonsvannsveien over the bridge and goes through the University area, giving access to all the houses situated in the south and south-west of the district.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	1.500 – 2.500
ADT Heavy	< 5 %
Speed limit	30 km/h
Street facilities	Poor sidewalks on residential streets, many are shared use, and a few paths through open field
Crossing facilities	Mostly not marked or signalized (not necessary)

Table 42

3.2.2- *Medium High frequency*

- Casparis – Bergsbakken

This is a corridor that scarcely appears on the shortest routes. It absorbs most of the routes from the east part of the district and crosses Eidsvolls gate avoiding the complex intersection, traversing a pedestrian crossing that is not regulated with traffic lights. This will be commented on in the next section in more detail.

The following table shows the main characteristics:

Corridor Characteristics	
ADT	Only at intersections
ADT Heavy	< 5 %
Speed limit	Mostly 30 km/h, at intersections could be higher
Street facilities	Mostly shared use
Crossing facilities	Marked and signalized, no traffic lights on major streets.

Table 43

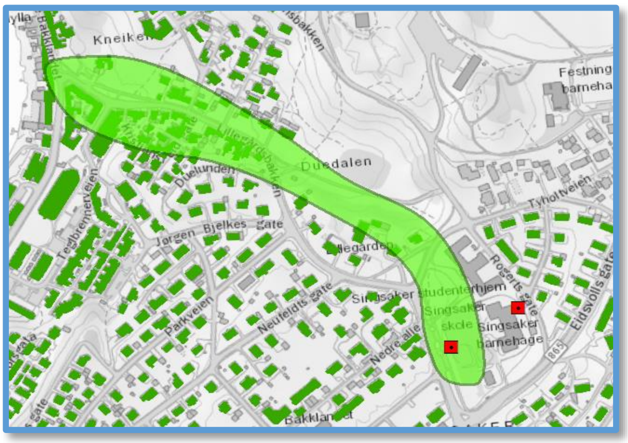


Figure 49 - Schmidts – Tyholtveien

Figure 50 - Lillegårdsbakken - Jonsvannsveien

Figure 51 – Left: Øvre Alle, Right: Casparis – Bergsbakken

4- WHAT ARE THE PREFERRED ROUTES BY CHILDREN?

4.1- Findings

To answer this question we are going to make use of the school reports provided by Trondheim Kommune. It was not possible to obtain individual routes for each child because this might be considered as sensitive information; therefore, only a map with all the routes merged together on it was provided. A higher resolution map is included in *Map Set Appendix 3J - Singsaker Children's Route***.**

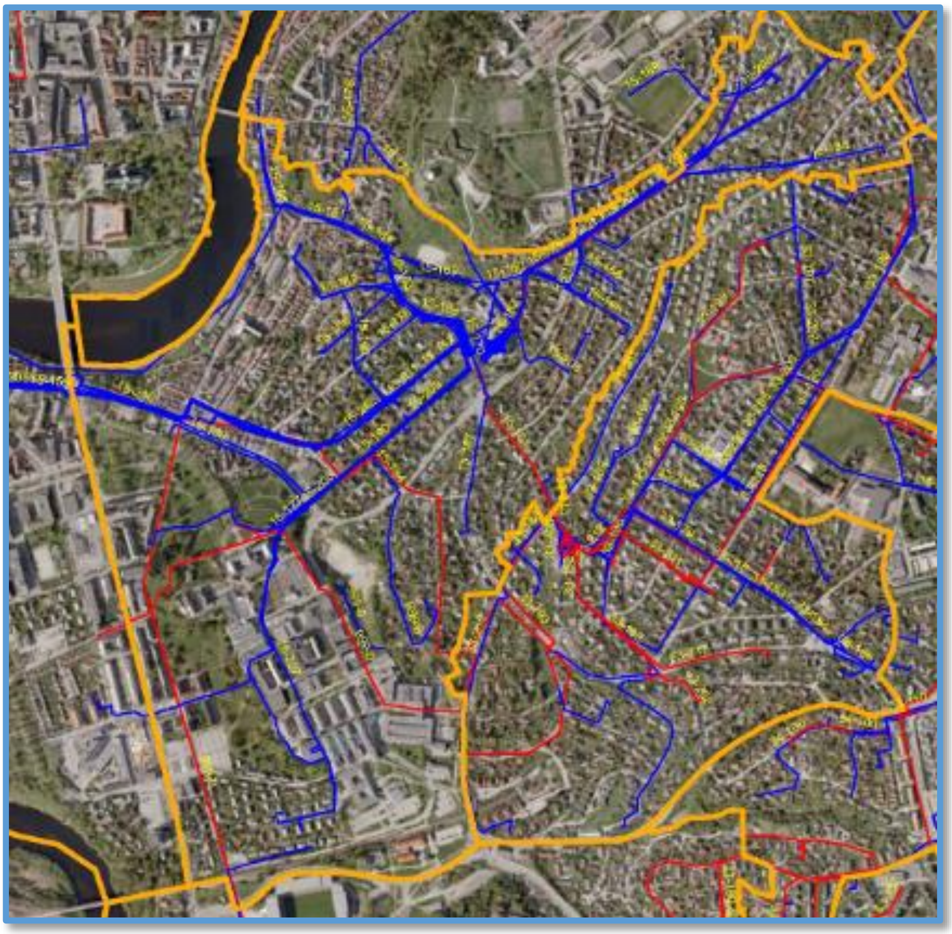


Figure 52 – Children Actual Routes; Blue: Secure, Red: Insecure

What we find is that children walk along corridors that are a combination of the shortest and the most secure ones, with a clearly higher tendency to seek the shorter path first. It is only in locations with a high feeling of insecurity where they appear to look for a better option. The findings of special interest are:

4.1.1- Bridge over Eidsvolls Gate

The current routes clearly seek to cross Eidsvolls Gate via the bridge which is also something that can be observed on the most secure paths, while the shortest routes provide a number of other choices. In this case, there is obviously a high insecurity cost saving on crossing the street by using the bridge.

Figure 53 - Bridge over Eidsvolls Gate

4.1.2- Kristianstensbakken Street

Current routes show that some children walk along Kristianstensbakken, a path included in the shortest corridors and which is completely avoided on the most secure paths because of a lack of sidewalk. Nevertheless, a number of children are taking this risk.

Figure 54 - Kristianstensbakken Street

4.1.3- *Eidsvolls Gate*

Current routes shows very few children walking along Eidsvolls Gate, something that is also possible to find on the shortest and most secure corridors but more clearly on the second ones. The reasons could be an overall sense of the presence of motorized traffic together with a loss of attractiveness because it is a steep street. This might lead children to look for both flatter and more secure paths.

Figure 55 - Eidsvolls Gate

4.1.4- *The signalized regulated intersection at Eidsvolls Gate*

Here we obtain an interesting finding. If we observe the shortest routes, children might cross this intersection to reach the school in the least time possible. However, on the map with the current routes, we see children crossing at the other two intersections located before and after the regulated intersection. And finally, by consulting the map with most secure routes, we observe a different approach and we can see how the routes avoid the main intersection at Eidsvolls Gate. Therefore, what we notice is that children does not see a safer intersection as attractive and instead, they cross the street at other locations. Why is this happening?

A possible explanation could be that even though the regulated intersection is safer than the other two ones, the streets that merge with the intersection have a higher feeling of insecurity (higher impedance cost). Therefore, on average, children prefer to take higher risks for a shorter period of time by crossing the street at the two other locations rather than walking for a longer period of time along a street with a greater impedance cost. This idea is better illustrated in the following figure:

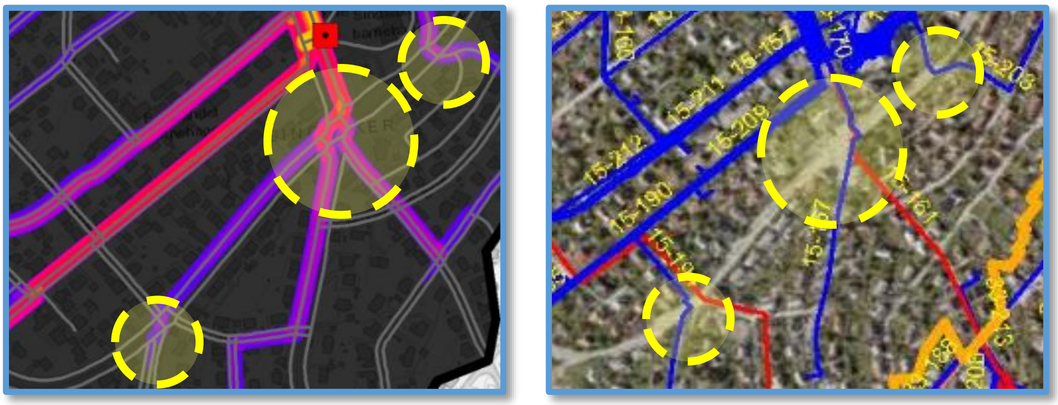


Figure 56 - Left: Shortest routes, Right: Actual routes

Figure 57 – Most secure routes

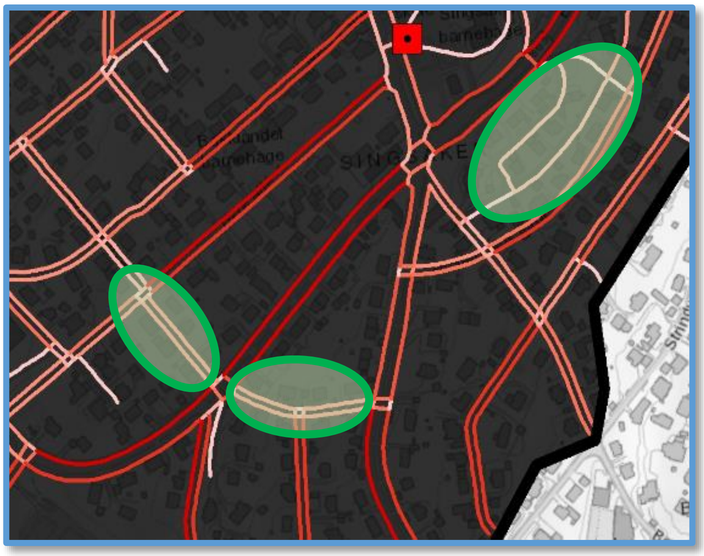


Figure 58 - Feeling of Insecurity Impedance Index, Clear Red: Low, Dark Red: High

4.2- Statistical comparison

In this section we are going to explain similarities and differences between the shortest routes, the current routes and the routes with the lowest level of insecurity.

Analyzing all the routes with SPSS we obtain the following table:

Statistics					
		Walking Time - Shortest Routes	**Insecurity - Shortest Routes**	**Walking Time - Safest Routes**	**Insecurity - Safest Routes**
N	**Valid**	1351,000	1351,000	1351,000	1351,000
	Lost	,000	,000	,000	,000
Mean		485,171	140,018	621,425	89,784
Mode		286,726	104,942	377,526	72,842
Standard Deviation		281,849	75,520	429,231	42,568
Asymmetry		1,358	,793	1,828	,399
Error standard de asymmetry		,067	,067	,067	,067
Curtosis		2,060	1,912	3,737	-,256
Error standard de Curtosis		,133	,133	,133	,133
Minimum		17,576	3,208	17,576	3,208
Maximum		1535,229	583,836	2298,062	219,103
Percentile	**25**	299,344	90,770	361,190	58,723
	50	421,497	134,921	528,997	86,177
	75	592,817	184,794	720,701	116,988

Table 44

As summarize of this table, we present two important conclusions:

- On average, routes with the lowest feeling of insecurity are a **30% longer** than shortest routes.
- On average, shortest routes have a **55% more of insecurity feeling** than the routes with the lowest feeling of insecurity.

Another important conclusion is that as long as the street network has a homogenous insecurity level, the most secure paths will be very close to the shortest path (as insecurity is related to walking time). In the opposite side, a hetereogeneous street network might lead to significantly large differences between both routes.

In the case of Singsaker School, we could say that it is somewhat heterogeneous. That means that we have streets of several levels of insecurity.

5- WHERE COULD WE IMPROVE THE FEELING OF SECURITY?

5.1- *Identifying potential location for improvements*

We should first try to improve those streets included on the shortest routes as they are more likely to be chosen by children on their journey to school. When it is not possible to improve the feeling of security on those routes, we should identify the most walked routes that are not the shortest ones, and search for locations that could be improved.

By taking action in this way, we ensure that implementing a countermeasure on a short corridor will be effective on a high percentage of children's routes and therefore on their accessibility to school.

It is also possible to identify specific locations outside the shortest routes and the most walked routes and to consider improvements there. These locations are typically situated close to the school boundary and though they are not used by the majority of the children they are still locations that should be assessed. However, in this case, just a few routes will benefit from implementing countermeasures.

From now on we will suggest a number of measures and it may be possible that some of them are not registered in Norwegian Legislation. However, as the model has been built including some of the measures utilized as a useful tool in various countries, when we suggest a measure not included in the legislation, we will mention this and we will suggest an alternative one of similar characteristics that is included in Norwegian Standards.

We will mention first those measures not included in Norwegian Standards:

- 20 km/h on very narrow streets or streets categorized as "Shared Use". This measure has been implemented in Spain since January 2017. Our model can work with this speed limit and therefore, in order to see such an effect on the street network, it will be used.
- Sidewalk at pedestrian crossing colored in the same color as cycle lanes and differing from the carriageway sidewalk (maintaining white markings) at locations close to the school. This measure is also quite common in Spain, the UK and many other countries.

Here we list the improvements that this research suggests, and the correspondent Appendix for more detail:

Countermeasure Nº	Location	Problem found	Suggested improvement	Appendix
1	Kristianstensbakken	No sidewalk	**Build a 2m sidewalk on one side**	5A
		Speed limit	**Set 20 km/h speed limit**	
		-	**Children sign (Nº142)**	
2	Rogers Gate	No sidewalk on right side Narrow sidewalk on left side	**Build a 2m sidewalk on right side**	5B
		School Zone	**Set 20 km/h speed**	
3	Schmidts Gate	School Zone	**Set 20 km/h speed**	5C
4	Eidsvoll Gate	Crossing not raised, poorly marked	**Raise crossing and improve markings**	5D
		-	**Children sign (Nº142)**	
5	Eidsvoll Gate	Poorly marked	**Improve markings**	5E
		-	**Children sign (Nº142)**	
6	Eidsvoll Gate	Busy intersection at peak hours	**Adult Cross Guards**	5F
7	Eidsvoll Gate	Poorly marked	**Improve markings**	5G
		-	**Children sign (Nº142)**	
8	Ovre Alle	Speed Limit	**Set 20 km/h speed limit**	5H
		-	**Children sign (Nº142)**	

Countermeasure Nº	Location	Problem found	Suggested improvement	Appendix
9	Nedre Alle	No sidewalk	**Build a 2m sidewalk on one side**	5I
		Speed limit	**Set 20 km/h speed limit**	
10	Klaebuveien	Crossing not raised and not colored	**Improve markings**	5J
11	Jonsvannsveien	Speed limit at school zone	**Set 20 km/h speed limit**	5K
		Crossing not raised or colored	**Improve markings**	
		-	**Children sign (Nº142)**	
12	Tyholtveien	Narrow sidewalks	**Build a 2m sidewalk where required**	5L
		-	**Children sign (Nº142)**	
13	Strindvegen	No refugee island	**Install refugee island**	5M
		-	**Children sign (Nº142)**	

Table 45 - Counter Measures

Now we can repopulate our network with the new values in the correspondent attribute field. With regard to links, we have basically focused on suggesting a very low speed limit close to the school zone on those routes that are usually walked by children. Moreover, where sidewalks were too narrow or nonexistent we have suggested building a 2m width sidewalk. Finally, we have suggested implementing children signs that make vehicle drivers aware of the presence of children when circulating very close to the school.

Regarding pedestrian crossings, we have selected those included on key routes to school and we have suggested raising them up and improving their visibility by coloring the sidewalk and maintaining white marks. Also, at the important intersection at Eidsvoll Gate, close to the school, we have suggested considering an adult cross guard at peak hours in both the morning and evening.

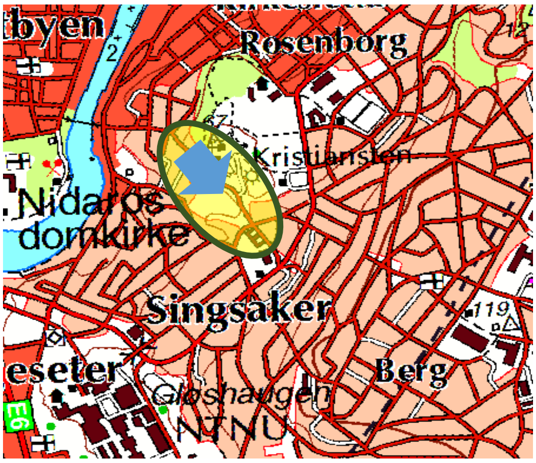
APPENDIX 5A	
Suggested Countermeasures	-Build a 2m sidewalk on one side -Set 15 km/h speed limit -“School route” signal
Location	
	
Street Name	Kristianstensbakken
Problem description	This is a street included in frequently walked routes to school which has been found without sidewalk and speed limit of 30 km/h.
Objectives	Since this streets is very close to the school zone we suggest building a 2 metres width sidewalk on the side closest to the hill, setting the speed limit to 20 km/h, and installing a signal post indicating children walking.
Cost	Low cost measure

Figure 59 - Example Countermeasure Appendix

5.2- Before/after countermeasures

Once we have rebuilt our network, we can calculate again the service areas and therefore we obtain a new accessibility map with our countermeasures implemented:

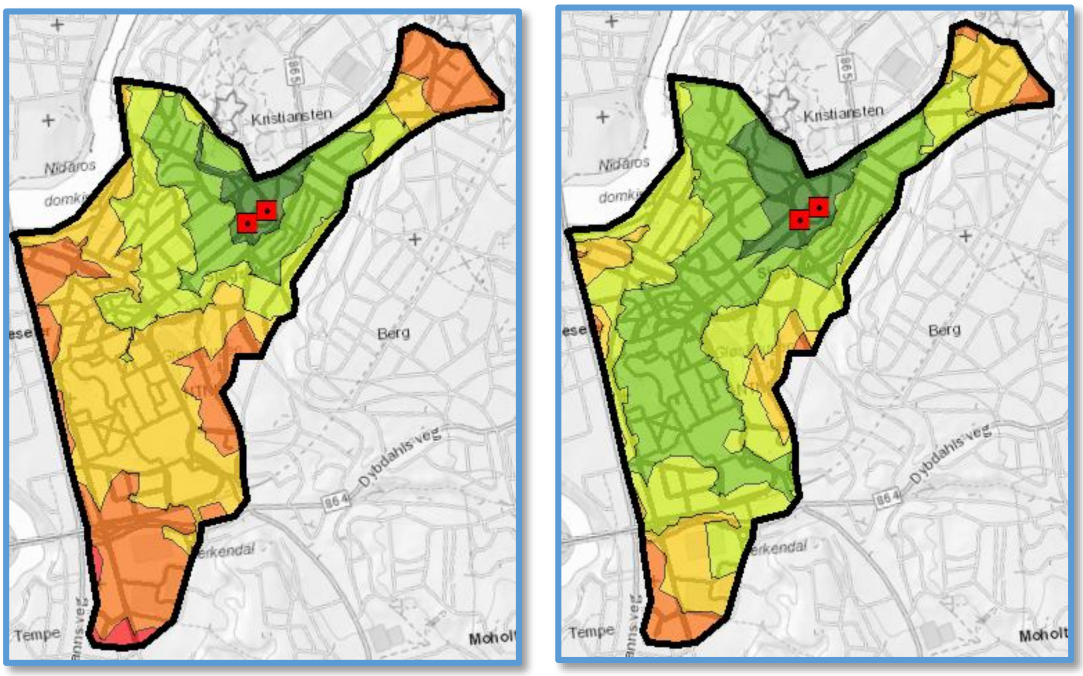


Figure 60 - Comparison before and after countermeasures

As shown in the figure above, the green area has been extended considerably with just a few measures at very low cost. This is because, thanks to our route analysis we have identified which routes are more likely to be walked by children and thus, by implementing measures on these streets, the majority of children benefit from such measures. The green area is now almost double, while the red area has completely vanished.

The next step after this study is to assess using the Traffic Safety Audit in order to validate the results drawn from this report.

A map in higher resolution can be found in *Map Set Appendix 5H – Accessibility (Countermeasures)***.**

After applying the indicated countermeasures indicated in *Table 15 – Countermeasures*, the results can be checked in the following table. We can conclude that countermeasures applied on key routes to schools result in a 40% increase of the green service area (<75 seconds of insecurity), and an average reduction of "25 seconds of insecurity" for each route.

Some other interesting results can be commented on:

- After measures are implemented, 82% of children are under 75 seconds of insecurity, which means that more than 300 new houses benefit from such measures (previously, 42%).
- Only 5% of all houses remain in the range 100 – 150 seconds of insecurity (previously, 23%).

Insecure Time to School (Comparison before and after countermeasures)												
Insec. Time	**Nº of residential buildings**			**% out of the total**			**Area (Ha)**			**% Area**		
Service Area	**Before**	**After**	**Dif.**	**Before**	**After**	**Dif.**	**Before**	**After**	**Dif.**	**Before**	**After**	**Dif.**
< 20 sec	31	66	**+35**	2%	6%	**+4%**	6	12	**+6**	4%	8%	**+4%**
< 50 sec	273	464	**+191**	20%	41%	**+21%**	24	63	**+39**	15%	40%	**+25%**
< 75 sec	307	401	**+94**	23%	35%	**+13%**	27	50	**+23**	17%	32%	**+15%**
< 100 sec	285	149	-136	21%	13%	-8%	58	24	-34	37%	15%	-22%
< 150 sec	223	53	-170	17%	5%	-12%	39	8	-31	25%	5%	-20%
> 150 sec	14	0	-14	1%	0	-1%	3	0	-3	2%	0%	-2%

Table 46 - Comparison before and after countermeasures

CHAPTER VI:

Conclusions, Discussion and Recommendations

VI) CONCLUSION, DISCUSSION AND RECOMMENDATIONS

1- CONCLUSSIONS

We are now going to briefly answer all of the research questions proposed at the beginning of this Master's thesis project:

1.1- What is the accessibility of the school?

After thorough network analysis of both the shortest routes and the routes with the lowest feeling of insecurity we can conclude that:

- Almost all the residential houses (96%) within the school boundary are under the maximum walking time allowed of 25 minutes. However, looking at the map showing the routes that children drew, many of them live outside the school boundary and therefore they might walk further than the maximum considered.
- We have set a maximum insecurity time of 10% of 25 minutes, which is 150 seconds. No child should be outside this service area, and after route analysis, we have found 2% of children outside this area and 23% of children within the range of 100-150 seconds.

1.2- What are the shortest routes and the most secure ones?

Calculating routes from each residential house to the school we have found:

- We have identified a total of six pedestrian corridors when analysing the shortest route to school. Some of them will cross important intersections and some of them will have a lack of infrastructure.
- The same analysis performed with a different variable such as the one defined as "feeling of insecurity" results in four corridors with the lowest feeling of insecurity. The model used in this project avoids complex intersections and streets with narrow sidewalks, high speed limits and heavy vehicle traffic and aims for wide sidewalks, low speed limits and little vehicle traffic.

1.3- What are the routes preferred by children?

- After analyzing actual routes, shortest routes and routes with the lowest feeling of insecurity we can conclude that:
- Children appear to look for the shortest route when walking to school, and only when crossing busy streets or complex intersections do they seem to look for an alternative route and shift to a safer route.
- In many cases, children on the same street seem to avoid safer and larger intersections but take risks on smaller and more unsafe intersections.
- On average, routes with the lowest feeling of insecurity are 30% longer than the shortest routes.
- On average, the shortest routes have 55% higher feeling of insecurity than the routes with the lowest feeling of insecurity.

1.4- Where could we improve the feeling of insecurity?

- We should first try to improve those streets included on the shortest routes as they are more likely to be chosen by children on their journey to school. When it is not possible to improve the feeling of security on those routes, we should identify the most walked routes that are not the shortest ones, and search for locations that could be improved.
- We have identified a total of 13 locations where we have suggested countermeasures. These measures are mostly applied within the school zone and on key routes to school.
- After measures, 82% of children are under 75 seconds of insecurity, which means that more than 300 additional houses benefit from such measures (previously, 45%).
- Only 5% of all houses remain in the range 100 – 150 seconds of insecurity (previously, 23%).

2- DISCUSSION

2.1- What is the purpose of the "feeling of insecurity" model?

The purpose of this "feeling of insecurity" model is to identify potential locations on a map where pedestrians might have the feeling that the street network is not meeting their needs in terms of traffic, comfort or walkability.

The model analysed streets, crossings and traffic flow both separately and as a whole. Therefore, it is possible to study which of these three factors are responsible for the shortcomings of the network. Moreover, the model can be used to study several scenarios by focusing on just one of the three previous mentioned factors, or for example in before/after countermeasures scenarios where it is possible to see the effects of implanting certain types of measures.

Finally, it can be used in conjunction with many other impedance attributes such walking time and slope impedance…

2.2- How reliable is the "feeling of insecurity model"?

First of all, we must point out that this model cannot be used for predicting traffic accidents and can only be used as a complementary study in Traffic Safety Analysis. This methodology is based on the perception of people and therefore, with different subjects at different locations and different questionnaires, results might vary.

However, the idea of rating and ranking the streets according to their infrastructure within the urban form can be extremely useful, since before accidents happen, city, urban and transport planners can gain insight into where the street network is weak and where it can be improved.

This methodology also demonstrates a method of measuring the lack of infrastructure when walking and crossing streets, which gives the possibility of comparison between "before" and "after" scenarios and between different locations or different interest points in the same city.

It should be mentioned that the methodology for choosing a school, building a network for pedestrians, and performing network analysis is independent of the impedance model used. This means that if we change the impedance model, we will clearly get different results but the methodology remains untouched.

2.3- How accurate is the street network?

An extremely accurate network that represents where pedestrians can walk or cross the street will require a tremendous amount of work, as each street must be recorded twice (once for each side of the street).

Therefore, the methodology for building a network for pedestrians presented in this Master's thesis demonstrates a rapid technique for creating an entirely new network from a car orientated network. Sidewalks and pedestrian crossings might not be placed in the exact position but they still give a reliable approximation that accurately represents where they walk and cross.

The decision to use a 2D network instead of a 3D one is mainly because of the absence of an accurate 3D terrain model. Differences in distance are evident between the two models but they will not be significant for route analysis.

2.4- What is the relation between feeling of insecurity and traffic safety?

"Feeling of insecurity" is an attempt to measure how people feel on streets according to the existing infrastructure. It means that streets with wide sidewalks, low speed limits and traffic volume, or pedestrian crossings with good facilities are given the best scores. It is thus measuring a subjective perception.

"Traffic Safety" refers to the methods and measures used to prevent road users from being killed or seriously injured. Methodologies such as EuroRAP or iRAP rate streets according to their survivability.

There might be a relation between these two terms, as the best rated streets using the first terminology might have a good survivability index. However it cannot be used for predicting accidents as the model does not use variables such as "risk", "accident probability", or "number of accidents", among many others.

2.5- Why some measures are not included in Norwegian Legislation?

The model has been built using material from several sources, though this mostly comes from guidelines and manuals produced in the Unites States, by the Norwegian Public Road Administration, and from Spain.

Therefore, the model includes infrastructures, facilities and countermeasures from all of these aforementioned countries. Measures suggested in *Chapter V – The Study Case of Singsaker School* are at times not included in Norwegian legislation, and in these cases alternative legal measures with similar characteristics are suggested.

However, as our model can work with the measures not included in Norwegian Legislation, we still make use of them in order to perform analysis and to show the results that they might produce.

3- RECOMMENDATIONS

For further research or improvement we suggest:

3.1- Using a 3D network

In order to perform a more accurate analysis, a 3D street model is suggested as this type of model can provide a more reliable distance calculation than the one calculated with a 2D street model and also, it is possible to perform inclination analysis to look for an additional impedance cost attribute based on the effort of going uphill.

A realistic model of the city in 3D is required in order to project the 2D network over the terrain and thus obtain the elevation or height coordinate. An alternative method is to obtain the centreline of each sidewalk or crossing by using a GPS which is able to record the elevation of routes.

3.2- Use objective formula instead of subjective, to predict accidents

As mentioned before in the "Discussion Section", the methodology proposed could be reutilized by replacing only the impedance cost attribute of "feeling of insecurity" with another one. Looking for a methodology that instead of measuring how people feel in the streets, measures the likelihood that a pedestrian will have an accident and its severity, is a possible topic for further research. In this case, using a methodology based on traffic safety parameters, it could be used to prevent accidents.

The network has the capability of storing many impedance attributes at the same time. Therefore, with just one street network, is possible to perform several analyses for each impedance attribute.

3.3- Develop a tool for ArcGIS that simplifies the process

Working throughout with ArcGIS for network analysis has been a very time-consuming process that could be greatly reduced by developing a tool that simplifies the entire process. The methodology is easy to implement in Python language or by using the included tool box "Tool Builder" in ArcGIS. Therefore, this type of tool development is suggested for further research.

Automatizing the process is of immense help and ArcGIS gives the user the ability to easily build their own tools in "Tool Builder". Moreover, these can be shared with many other users all over the world.

3.4- Comparison between 3-4 schools within the same city

Because of the limited time available for completion of this Master's thesis, it has not been possible to study more than one school due to the large amount of data which had to be collected and the time-consuming process of network analysis. Therefore, it is suggested that in future studies, between 3-4 schools within the same city at different locations should be considered in order to identify differences and similarities.

Not only would the study of 3-4 schools within the same city be of interest, but also the study and comparison of different cities within the same country as well as comparisons between cities in different countries.

3.5- Analyze individual routes

And finally, a better network analysis could have been done by analyzing every single route for a child when walking to school. Because this type of data was considered sensitive, it was not possible to obtain such information, and therefore, only the study of the routes as a whole has been possible. For further research, the study of single routes is suggested.

REFERENCES

REFERENCES

ASMA ALI & CRISTEI, C. 2009. Rating Urban Street for Pedestrian Facilities Based on User's Perception-. *George Mason University*.

AULTMAN-HALL, L., HALL, F. & BAETZ, B. 1997. Analysis of Bicycle Commuter Routes Using Geographic Information Systems: Implications for Bicycle Planning. *Transportation Research Record: Journal of the Transportation Research Board*, 1578**,** 102-110.

AUSTIN, K., TIGHT, M. & KIRBY, H. 1997. The use of geographical information systems to enhance road safety analysis. *Transportation Planning and Technology*, 20**,** 249-266.

AZIZ, I. S., ZAHARAH, M. Y., DASIMAH, O. & RAHMAN, A. N. N. A. 2014. GIS Route Network Analysis for Safe Journey to School. Unpublished.

BALLESTER, M. G. 2011. *Universal walkability assessment of urban pedestrian networks: The Mallorca Case Study*. Case Study, Utrecht University (UU), Wageningen University and Research Centre (WUR), Delft University of Technology (TUD) and the International Institute for Geo-Information Science and Earth Observation (ITC), Enschede.

BRIAN C. TEFFT 2011. Impact Speed and a Pedestrian's Risk of Severe Injury or Death. *AAA Foundation for Traffic Safety*

BROWN, A., MARCHETTI, L., PULLEN, N., SCULLY, M. & ZEEGER, C. 2015. Safe Routes to School Guidebook. *In:* CENTER, H. S. R. (ed.). North Carolina: Pedestrian and Bicycle Information Center of the University of North Carolina.

BRUSTLIN, V. H. 2000. FHWA GIS Safe Routes to School Tools Users Guide. Watertown: Vanasse Hangen Brustlin INC.

BURTT, R., HAYRE, S., BERGMAN, J. & PEREZ, A. 2013. Complete Street Design Guidelines. *In:* DEPARTMENT, T. O. W. P. W. (ed.). Windsor: Whitlock & Weinberger Transportation, Inc.

DESSING, D., DE VRIES, S., HEGEMAN, G., VERHAGEN, E. & PIERIK, F. 2016. Childrens route choice during active transportation to school: difference between shortest and actual route. *International Journal of Behavioral Nutrition and Physical Activity*, 13.

DOMINGO GÓMEZ, O. & MAURICIO GÓMEZ, V. 2011. Evaluación ambiental estratégica (EAE); un instrumento preventivo de gestión ambiental. *Revista de Salud Ambiental*, 11**,** 9-16.

ELVIK, R., VAA, T. & ERKE, A. 2009. *The Handbook of Road Safety Measures*, Bradford, Emerald Group Publishing Limited.

ESRI. 2017. *ArcGIS Online Help* [Online]. ESRI. Available: doc.arcgis.com/es/arcgis-online/.

EVERS, C., BOLES, S., JOHNSON-SHELTON, D., SCHLOSSBERG, M. & RICHEY, D. 2014. Parent safety perceptions of child walking routes. *Journal of Transport & Health*, 1**,** 108-115.

GARCÍA-TORRES FERNÁNDEZ, A. 2017a. *Percepción de la seguridad en las rutas hacia el colegio* [Online]. Trondheim: Typeform. Available: https://ntnutransport.typeform.com/to/AuKOKF.

GARCÍA-TORRES FERNÁNDEZ, A. 2017b. *Trafikksikkerhet i reisen til skolen* [Online]. Trondheim: Typeform. Available: https://ntnutransport.typeform.com/to/Ewv5Xs.

HARRISON, F., BURGOINE, T., CORDER, K., VAN SLUIJS, E. M. F. & JONES, A. 2014. How well do modelled routes to school record the environments children are exposed to?: a cross-sectional comparison of GIS-modelled and GPS-measured routes to school.(Report). *International Journal of Health Geographics*, 13.

HENARY, B. Y., CRANDALL, J., BHALLA, K., MOCK, C. N. & ROUDSARI, B. S. 2003. Child and adult pedestrian impact: the influence of vehicle type on injury severity. *Annual proceedings. Association for the Advancement of Automotive Medicine*, 47**,** 105.

HERNANE, B., DURVAL, L. N. & LLUÍZ, P. V. 2001. Behavioural impedance for route planing: Techniques from the pedestrian's perspective. *Congresso de Pesquisa e Ensino em Transportes*.

ILIR, B., RUTH, L. S., ALLISON, F. & JEFFREY, M. S. 2010. Using GIS to analyze the role of barriers and facilitators to walking in children's travel to school. *URBAN DESIGN International,* 16**,** 51.

ISSIDRO, C., PEDROSO, M., ZIMMERMAN, S. & ESPINOZA, D. 2013. A framework for GIS and safe routes school. Safe Routes to School National Partnership.

JACOBSEN, P. L. 2015. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention,* 21**,** 271.

JONSSON, T. 2005. *Predictive models for accidents on urban links - A focus on vulnerable road users.* 226, Lund university.

KELLY, J. A. & FU, M. 2014. Sustainable school commuting – understanding choices and identifying opportunities: A case study in Dublin, Ireland: A case study in Dublin, Ireland. *Journal of Transport Geography,* 34**,** 221-230.

KOMMUNE, T. 2012. Skole Veg Rapport 2012. Trondheim, Norway: Trondheim Kommune.

KOMMUNE, T. 2013. Barnetråkk 2009-2013, Singsaker Skole. Trondheim, Norway: Trondheim Kommune.

KRENN, P. J., TITZE, S. & OJA, P. 2014. Route choices of transport bicyclists: A comparison of actually used and shortest routes. *International Journal of Behavioral Nutrition and Physical Activity,* 11.

LAHART, J., CONROY, E., CURLEY, R., HOGAN, P., MCGRATH, S., MOLONY, D., STAPLETON, J., TAYLOR, D. & TAYLOR, J. 2014. Design Manual for Urban Roads and Streets. *In:* DEPARTMENT OF TRANSPORT, T. A. S. A. T. D. O. E., COMMUNITY AND LOCAL GOVERNMENT (ed.).

LARSEN, K., BULIUNG, R., FAULKNER, G. & LARSEN, K. 2013. Safety and School Travel How Does the Environment Along the Route Relate to Safety and Mode Choice? *Transportation Research Record***,** 9-18.

LARSEN, K., GILLILAND, J. & HESS, P. 2012. Route-Based Analysis to Capture the Environmental Influences on a Child's Mode of Travel between Home and School. *Annals of the Association of American Geographers,* 102**,** 1348-1365.

NASRUDIN, N. A. & NOR, A. R. M. 2013. Travelling to School: Transportation Selection by Parents and Awareness towards Sustainable Transportation. *Procedia Environmental Sciences,* 17**,** 392-400.

NPRA. 2017. *Norwegian Database Road Data* [Online]. Norwegian Public Road Administration. Available: https://www.vegvesen.no/vegkart/vegkart/.

PANTER, J. R., JONES, A. P., VAN SLUIJS, E. M. F. & GRIFFIN, S. J. 2010. Neighborhood, Route, and School Environments and Children's Active Commuting. *American Journal of Preventive Medicine,* 38**,** 268-278.

RECKER, W. W., CHEN, C. & MCNALLY, M. G. 2001. Measuring the impact of efficient household travel decisions on potential travel time savings and accessibility gains. *Transportation Research Part A,* 35**,** 339-369.

RICHARDS, D. C., STORBRITANNIA DEPARTMENT FOR, T. & TRANSPORT RESEARCH, L. 2010. Relationship between speed and risk of fatal injury : pedestrians and car occupants. El. utg. ed. London: DfT.

SCHWARTZ, W. L., PORTER, C. D., PAYNE, G. C., SUHRBIER, J. H. & III, P. C. M. A. W. L. W. 1999. Guidebook on methods to estimate non-motorized travel. Federal Highway Administration.

SIMON, H. A. 1960. *The new science of management decision,* New York, Harper & Row.

STATENS, V. & VEGDIREKTORATET 2014. Veg- og gateutforming : [håndbok N100]. Oslo: Vegdirektoratet.

TEFFT, B. C. 2013. Impact speed and a pedestrian's risk of severe injury or death. *Accid Anal Prev,* 50**,** 871-8.

VEGDIREKTORATET & STATENS, V. 2014. Gangfeltkriterier : [håndbok V127]. Oslo: Vegdirektoratet.

YEE, R., PARISI, D. & HONDORP, B. 2007. Creating a Citywide Safe Routes to School Program: Pasadena, CA, USA's Step-by-Step Approach. *Institute of Transportation Engineers. ITE Journal,* 77**,** 22-26.

APPENDIUM

APPENDIX 1A – INFORMATION LETTER

"Implementation of GIS based tools in Traffic Safety: Analysis of pedestrian/bikes routes and roads in the City of Trondheim”

Background and Purpose

The purpose of the project is to study which kind of route take children take between school and their homes either by bike or by foot (shortest- or safest), as well as the drop points where children get on/off the bus. The objective is to identify potential unsafe routes for children and implement measures to improve its safety. This project is a Master Thesis at the NTNU in Trondheim and will be supervised by the Department of Civil and Transport Engineering, with Professor Thomas Jonsson.

A group of children (volunteers) will be requested to draw their routes to/from schools on an online map application.

What does participation in the project imply?

School districts change during the planning period as a result of development and urban growth of the nearby areas. This may result in new congestion problems and dangerous intersections.

A continuous and close cooperation with the school and parent councils is very important to get good results. Several schools have worked actively raising measures for students, teachers and parents. Efforts to ensure traffic safety in the journey to school is never completely finished and needs to be updated continuously.

Therefore, it is necessary to draw a map with the most common routes among children when commuting to schools in order to build safe routes map, and implement measures in those routes that are potentially dangerous and more likely chosen by children. In this case, children will be requested to draw their routes using Google Maps on a computer room within school hours. Children will be split up in groups of 10-15 so that individual feedback can be provided. When all the routes are gathered up, they will be transferred manually to GIS software in order to work with vectorial data. No personal data such a name, ID, phone or other sensible information will be asked.

The approximate duration for a group of 15 students would be about 30 minutes. The total number of students involved should be around 90-120 (if possible). It is expected to last no more than one morning in total within school hours.

Parents are free to give consent on behalf of their children and to request to see the final drawn map with all the routes from the children that took part in the survey.

What will happen to the information about you?

All personal data will be treated confidentially. Only the Civil and Engineering Department will have access to this data, and it will be stored anonymously on a cloud server (previously encrypted).

None of the participants will be recognizable in the publication

The survey it is expected to be in Mars or in April. The project is scheduled for completion by June 2017.

Voluntary participation

It is voluntary to participate in the project, and you can at any time choose to withdraw your consent without stating any reason. If you decide to withdraw, all your data will be made disappear.

If you would like to participate or if you have any questions concerning the project, please contact:

- Alejandro García-Torres Fernández (researcher):
    - alexgtorres91@gmail.com +4746564730/+34662043235
- Thomas Jonsson (supervisor):
    - thomas.jonsson@ntnu.no +47 97495217

The study has been notified to the Data Protection Official for Research, NSD - Norwegian Centre for Research Data.

Consent for participation in the study

We, the parents/father/mother/person in charge, have received information about the project and let our child/children to participate voluntarily:

(Signed by the parents/mother/father, person in charge, date)

I have received information about the project and am willing to participate

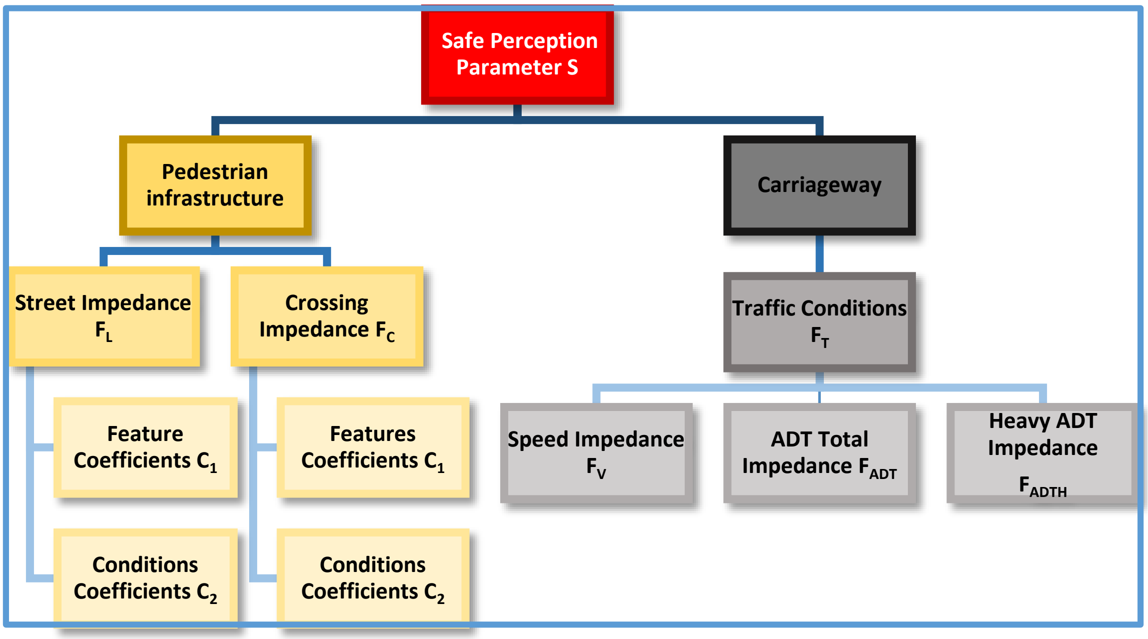
(Signed by participant, date)

APPENDIX 4A – STREET IMPEDANCE METHODOLOGY

Content:

- Street Impedance Formulas
- Route Feeling of Insecurity Impedance Index
- Link impedance index
    - Link impedance
    - Traffic Impedance
- Street Coefficient Tables
    - SECONDARY STREETS – COLLECTOR STREET
        - Features coefficients C1 with additional lanes required
        - Features coefficients C1 with no additional lanes
        - Conditions coefficients C2
    - Tertiary Links – LOCAL STREETS
        - Features coefficients C1 with additional lanes require
        - Features coefficients C1 with no additional lane
        - Conditions coefficients C2
    - RESIDENTIAL STREETS
        - Features coefficient C1 with on-parking permitted
        - Features coefficients C1 with no on-parking permitted:
        - Conditions coefficients C2
    - SHARED USE RESIDENTIAL STREETS
        - Shared use residential streets
        - Conditions coefficients C2

1- STREET IMPEDANCE FORMULAS



Can be defined as the subjective safe perception while walking along a link or crossing a street. The range of this value goes from 0 (Feeling of security) to 1 (Feeling of insecurity).

2- ROUTE FEELING OF INSECURITY IMPEDANCE INDEX:

Given a route walked by a pedestrian, the total impedance is the sum of all the links and pedestrian crossings that the pedestrian walk along:

$$I_S = \sum I_L + \sum I_C$$

Where:

- I_L = Link impedance
- I_C = Pedestrian crossing impedance

3- LINK IMPEDANCE INDEX:

For each link, the impedance will be calculated as follows:

$$I_L = \frac{L}{V_w} \times \mathrm{S} = \frac{L}{V_w} \times (AF_L + \mathrm{B}F_T)$$

Where:

- I_L = Feeling of Insecurity Impedance Index for a given link
- L = Length in meters

- V_w = Walking speed
- A = 0,47
- B = 0,53
- F_I = Link infrastructure impedance
- F_T = Traffic impedance

3.1- Link impedance:

This factor refers to the quality of the infrastructure for walking purposes. Wide pavements with buffers filled with trees or benches are given the best scores while streets without pavements or additional lanes are considered as having high impedance.

The rating of FL is from 0 (No impedance) to 1 (High impedance). In order to provide a link with a score, the existence of buffers, pavements, additional lanes for bicycles or parking and lighting have been taken into account.

$$F_L = \sum f_l = \sum C_1 C_2$$

Where:

- C_1 = Feature coefficient. It weighs the different features along a link according to the expert's preference ***(See section II for tables)***
- C_2 = Condition feature. It gives a score according to the condition of the feature **(See section II for tables)**

3.2- Traffic Impedance:

$$F_T = D \cdot F_V + E \cdot F_{ADT} + F \cdot F_{ADTH}$$

Where:

- F_V = Vehicle speed impedance
- F_{ADT} = ADT impedance
- F_{ADTH}= Heavy ADT impedance
- D = Speed weight = 0,46
- E = Total ADT weight coefficient = 0,33
- F = Heavy vehicle ADT weight coefficient = 0,21

Speed impedance FV			
Speed (km/h)	Risk of fatality	Risk of severe injured	Adopted index
20	1%	5 %	0,05
30	2 %	10 %	0,1
40	5 %	25 %	0,25
50	10 %	50 %	0,50
60	50 %	65 %	0,65
70	70 %	77 %	0,77
80	90 %	92 %	0,92
90	95 %	97 %	0,97
100	99 %	99 %	0,99
120	100 %	100 %	1.00

Table 47 – Speed Impedance

Traffic Impedance FAADT									
ADT	Root function	Log Function	Root coefficient	Log Coefficient	ADT Heavy	Root function	Log Function	Root coefficient	Log Coefficient
1	1,0	0,0	0,01	0,00	1	1,0	0,00	0,01	0,00
10	3,2	1,0	0,02	0,23	5	2,2	0,70	0,03	0,18
20	4,5	1,3	0,03	0,30	10	3,2	1,00	0,04	0,26
50	7,1	1,7	0,04	0,39	15	3,9	1,18	0,04	0,30
100	10,0	2,0	0,06	0,45	20	4,5	1,30	0,05	0,34
150	12,2	2,2	0,08	0,49	40	6,3	1,60	0,07	0,41
200	14,1	2,3	0,09	0,52	50	7,1	1,70	0,08	0,44
300	17,3	2,5	0,11	0,56	75	8,7	1,88	0,10	0,48
400	20,0	2,6	0,13	0,59	100	10,0	2,00	0,12	0,52
500	22,4	2,7	0,14	0,61	150	12,2	2,18	0,14	0,56
750	27,4	2,9	0,17	0,65	200	14,1	2,30	0,16	0,59
1000	31,6	3,0	0,20	0,68	300	17,3	2,48	0,20	0,64
1500	38,7	3,2	0,24	0,72	400	20,0	2,60	0,23	0,67
2000	44,7	3,3	0,28	0,75	500	22,4	2,70	0,26	0,70
3000	54,8	3,5	0,34	0,79	750	27,4	2,88	0,32	0,74
5000	70,7	3,7	0,44	0,84	1000	31,6	3,00	0,37	0,77
7500	86,6	3,9	0,54	0,88	1250	35,4	3,10	0,41	0,80
10000	100,0	4,0	0,63	0,91	1500	38,7	3,18	0,45	0,82
12500	111,8	4,1	0,70	0,93	2500	50,0	3,40	0,58	0,88
15000	122,5	4,2	0,77	0,95	3000	54,8	3,48	0,63	0,90
20000	141,4	4,3	0,88	0,98	4000	63,2	3,60	0,73	0,93
22500	150,0	4,4	0,94	0,99	5000	70,7	3,70	0,82	0,95
25000	158,1	4,4	0,99	1,00	7500	86,6	3,88	1,00	1,00

Table 48 - Traffic Volume Impedance

4- STREET COEFFICIENT TABLES

4.1- *Secondary Streets – Collector Street*

4.1.1- *Features coefficients C_1 with additional lanes required*

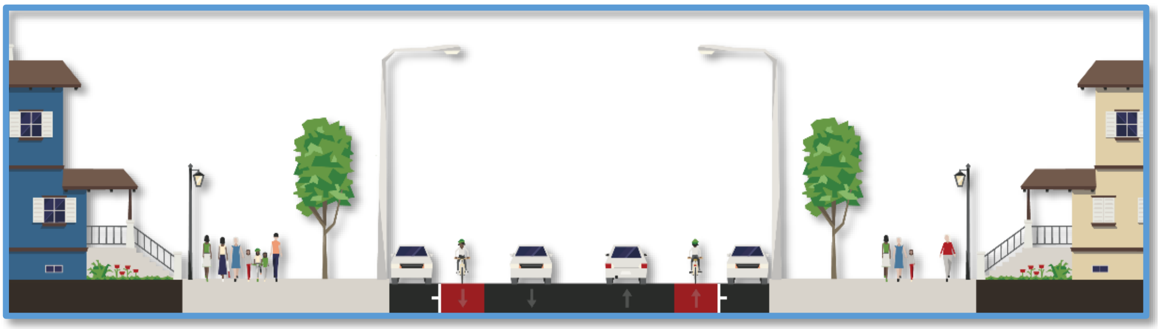


Figure 61 – Collector Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C1	Score	C1	Score	C1	Score	C1	Score	C1
NIGHT	14 %	0,14	22 %	0,22	22 %	0,22	22 %	0,22	19 %	0,19
DAY	17 %	0,17	27 %	0,27	28 %	0,28	27 %	0,22	-	-

Concept Design		
Speed limit	50 km/h	30 – 40 km/h
ADT range	0 – 15.000 ADT	0 – 15.000 ADT
Buffer and barriers	Recommended	Recommended
Pavements	Minimum 2m	Minimum 2m
Bike lanes	Required	Required if ADT > 4.000
Parking lanes	No permitted	Permitted if < 8.000
Bike and Parking lanes	No	Permitted if ADT < 8.000
Travel lanes	2	2
Accessibility	Limited driveways	Limited driveways

Table 49 - Collector Concept Design

4.1.2- Features coefficients C_1 with no additional lanes

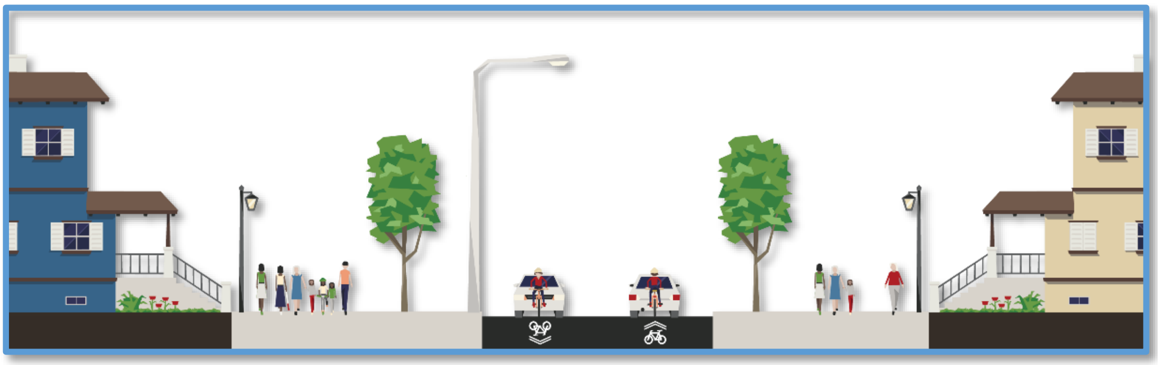


Figure 62 - Collector Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C1	Score	C1	Score	C1	Score	C1	Score	C1
NIGHT	20 %	0,20	33 %	0,33	34 %	0,34	-	-	13 %	0,13
DAY	23 %	0,23	38 %	0,38	39 %	0,39	-	-	-	-

Concept Design	
ADT range	0 – 15.000 ADT
Speed limit	30 - 40 km/h
Buffer and barriers	Recommended
Pavements	Minimum 2m
Bike lanes	-
Parking lanes	-
Bike and Parking lanes	-
Travel lanes	2
Accessibility	Limited driveways

Table 50 - Collector Concept Design

Feature Group	Condition	Score	C_2
Signalization	No school or speed signals	*0*	**1**
	Speed Signals	*50 %*	**0,5**
	School signals	*50 %*	**0,5**
	Both	*100 %*	**0**
Pavements	No pavement	*0*	**1**
	Narrow < 2m	*33 %*	**0,66**
	Normal 2-4 m	*66 %*	**0,33**
	Wide > 4 m	*100 %*	**0**
Buffer / Barriers	No buffer / barrier	*0 %*	**1**
	Narrow buffer < 1 m	*33 %*	**0,66**
	Normal buffer 1-3 m	*66 %*	**0,33**
	Wide buffer > 3 m	*100 %*	**0**
	barrier	*100 %*	**0**
Additional Lanes	Usually unoccupied	*33 %*	**0,66**
	Often occupied	*66 %*	**0,33**
	Normally occupied	*100 %*	**0**
	Bike lane	*50 %*	**0,5**
Lighting	No	*0*	**1**
	Poor conditions	*50 %*	**0,5**
	Good conditions	*100 %*	**0**

Table 51 - Collector Streets Condition Coefficients

4.2- Tertiary Links – Local Streets

4.2.1- Features coefficients C_1 with additional lanes required

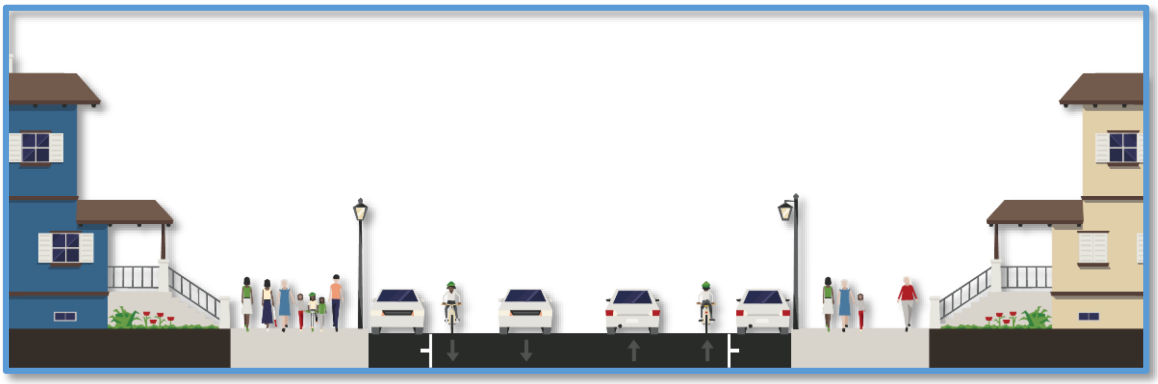


Figure 63 – Local Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C_1	Score	C_1	Score	C_1	Score	C_1	Score	C_1
NIGHT	18 %	0,18	30 %	0,30	-	-	30 %	0,30	12 %	0,12
DAY	23 %	0,23	39 %	0,30	-	-	38 %	0,38	-	-

Concept Design	
ADT range	0 – 8.000 ADT
Speed limit	30 - 40 km/h
Buffer and barriers	Not necessary
Pavements	Minimum 2m
Bike lanes	Required if ADT > 4.000
Parking lanes	Permitted if ADT < 8.000
Bike and Parking lanes	Permitted if ADT < 8.000
Travel lanes	2
Accessibility	Limited driveways

Table 52 – Local Streets Concept Design

4.2.2- *Features coefficients C_1 with no additional lanes*

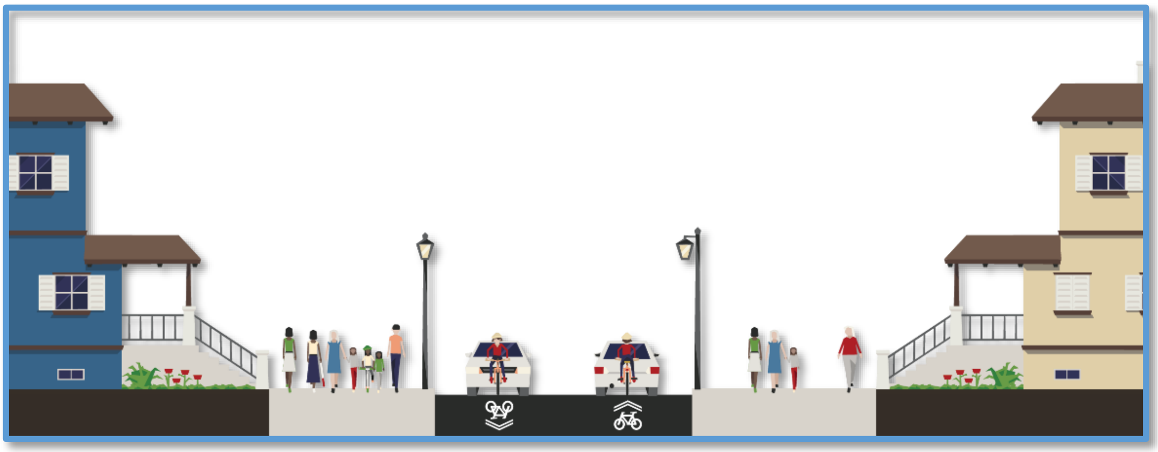


Figure 64 - Local Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C_1	Score	C_1	Score	C_1	Score	C_1	Score	C_1
NIGHT	30 %	0,30	50 %	0,50	-	-	-	-	19 %	0,19
DAY	38 %	0,38	62 %	0,62	-	-	-	-	-	-

Concept Design	
ADT range	0 – 8.000 ADT
Speed limit	30 - 40 km/h
Buffer and barriers	Not necessary
Pavements	Minimum 2m
Bike lanes	-
Parking lanes	-
Bike and Parking lanes	-
Travel lanes	2
Accessibility	Limited driveways

Table 53 - Local Streets Concept Design

4.2.3- Conditions coefficients C_2

Feature Group	Condition	Score	C_2
Signalization	No school signals	*0*	**1**
	Speed Signals	*50 %*	**0,5**
	School signals	*50 %*	**0,5**
	Both	*100 %*	**0**
Pavements	No pavement	*0*	**1**
	Narrow < 2m	*33 %*	**0,66**
	Normal 2-4 m	*66 %*	**0,33**
	Wide > 4 m	*100 %*	**0**
Buffer / Barriers	No buffer / barrier	-	**-**
	Narrow buffer < 1 m	-	**-**
	Normal buffer 1-3 m	-	**-**
	Wide buffer > 3 m	-	**-**
	barrier	-	**-**
Additional Lanes	Usually unoccupied	*33 %*	**0,66**
	Often occupied	*66 %*	**0,33**
	Normally occupied	*100 %*	**0**
	Bike lane	*50 %*	**0,5**
Lighting	No	*0*	**1**
	Poor conditions	*50 %*	**0,5**
	Good conditions	*100 %*	**0**

Table 54 - Local Streets Conditions Coefficients

4.3- Residential Streets

4.3.1- Features coefficient C_1 with on-parking permitted

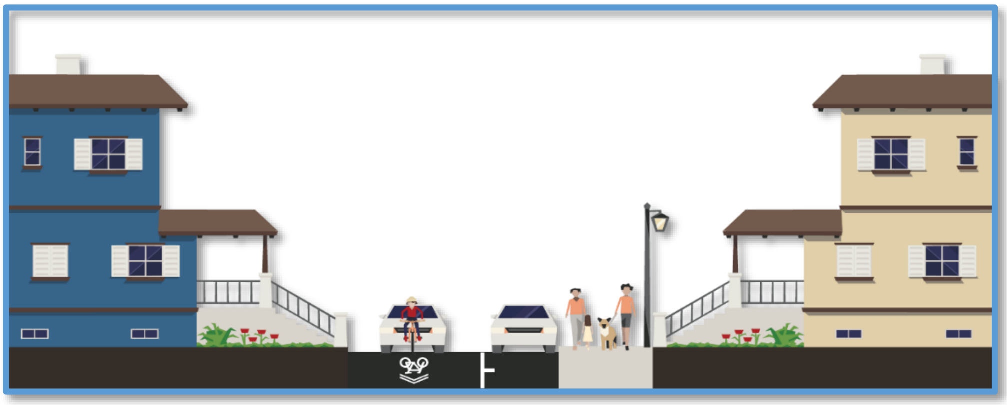


Figure 65 - Residential Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C_1	Score	C_1	Score	C_1	Score	C_1	Score	C_1
NIGHT	19 %	0,18	35 %	0,30	-	-	32 %	0,30	14 %	0,12
DAY	23 %	0,23	39 %	0,30	-	-	38 %	0,38	-	-

Concept Design	
ADT range	0 – 2.000 ADT
Speed limit	30 - 40 km/h
Buffer and barriers	Not necessary
Pavements	At least one sided
Bike lanes	-
Parking lanes	Permitted if < ADT 8.000
Bike and Parking lanes	-
Travel lanes	1
Accessibility	Limited driveways

Table 55 - Residential Streets Concept Design

4.4- Features coefficients C_1 with no on-parking permitted:

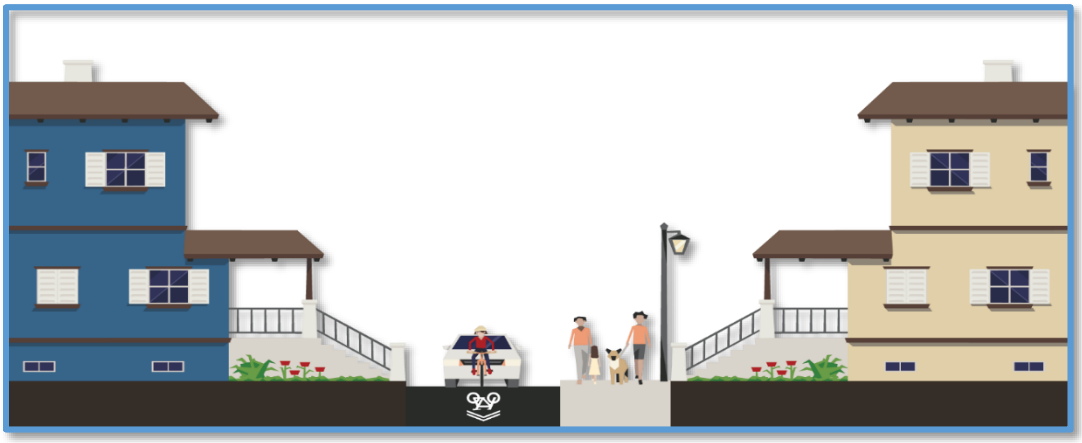


Figure 66 - Residential Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C_1	Score	C_1	Score	C_1	Score	C_1	Score	C_1
NIGHT	30 %	0,30	50 %	0,50	-	-	-	-	19 %	0,19
DAY	38 %	0,38	62 %	0,62	-	-	-	-	-	-
Concept Design										
ADT range	0 – 2.000 ADT									
Speed limit	30 - 40 km/h									
Buffer and barriers	Not necessary									
Pavements	At least one sided									
Bike lanes	-									
Parking lanes	-									
Bike and Parking lanes	-									
Travel lanes	1									
Accessibility	Limited driveways									

Table 56 - Residential Streets Concept Design

4.4.1- Conditions coefficients C_2

Feature Group	Condition	Score	C_2
Signalization	No school signals	*0*	**1**
	Speed Signals	*50 %*	**0,5**
	School signals	*50 %*	**0,5**
	Both	*100 %*	**0**
Pavements	No pavement	*0*	**1**
	Narrow < 2m	*33 %*	**0,66**
	Normal 2-4 m	*66 %*	**0,33**
	Wide > 4 m	*100 %*	**0**
Buffer / Barriers	No buffer / barrier	-	**-**
	Narrow buffer < 1 m	-	**-**
	Normal buffer 1-3 m	-	**-**
	Wide buffer > 3 m	-	**-**
	barrier	-	**-**
Additional Lanes	Usually unoccupied	*33 %*	**0,66**
	Often occupied	*66 %*	**0,33**
	Normally occupied	*100 %*	**0**
	Bike lane	*50 %*	**0,5**
Lighting	No	*0*	**1**
	Poor conditions	*50 %*	**0,5**
	Good conditions	*100 %*	**0**

Table 57- Residential Streets Conditions Coefficients

4.5- Shared Use Residential Streets

4.5.1- Shared use residential streets

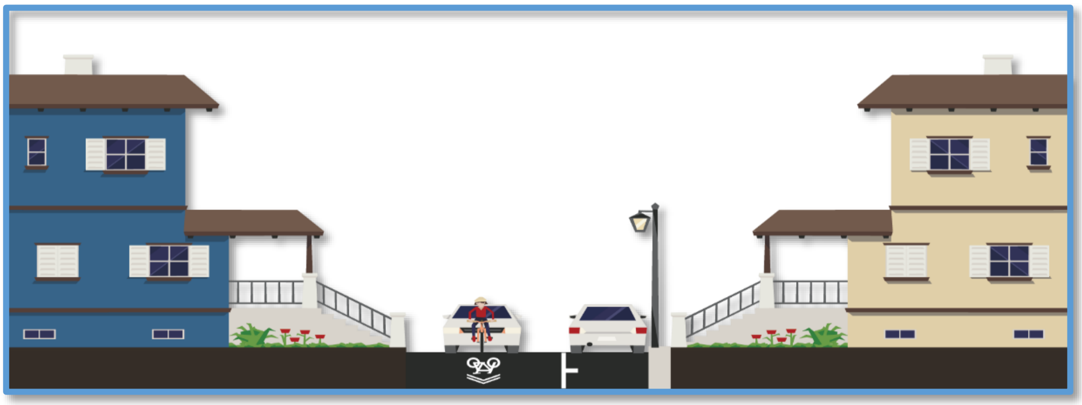


Figure 67 - Shared Street Cross Section

TIME	Signalization		Pavements		Buffers/Barriers		Additional Lanes		Lighting	
	Score	C_1	Score	C_1	Score	C_1	Score	C_1	Score	C_1
NIGHT	-	-	-	-	-	-	-	-	100 %	1
DAY	-	-	-	-	-	-	-	-	-	-

Concept Design	
ADT range	0 – 200 ADT
Speed limit	30 km/h
Buffer and barriers	Not necessary
Pavements	Not necessary
Bike lanes	-
Parking lanes	-
Bike and Parking lanes	-
Travel lanes	1
Accessibility	Limited driveways

Table 58 - Shared Streets Concept Design

4.5.2- Conditions coefficients C_2

Feature Group	Condition	Score	C_2
Signalization	No school signals	-	**-**
	Speed Signals	-	**-**
	School signals	-	**-**
	Both	-	**-**
Pavements	No pavement	-	**-**
	Narrow < 2m	-	**-**
	Normal > 2 m	-	**-**
Buffer / Barriers	No buffer / barrier	-	**-**
	Narrow buffer < 1 m	-	**-**
	Normal buffer 1-3 m	-	**-**
	Wide buffer > 3 m	-	**-**
	barrier	-	**-**
Additional Lanes	Usually unoccupied	-	**-**
	Often occupied	-	**-**
	Normally occupied	-	**-**
	Bike lane	-	**-**
Lighting	No	*0*	**1**
	Poor conditions	*50 %*	**0,5**
	Good conditions	*100 %*	**0**

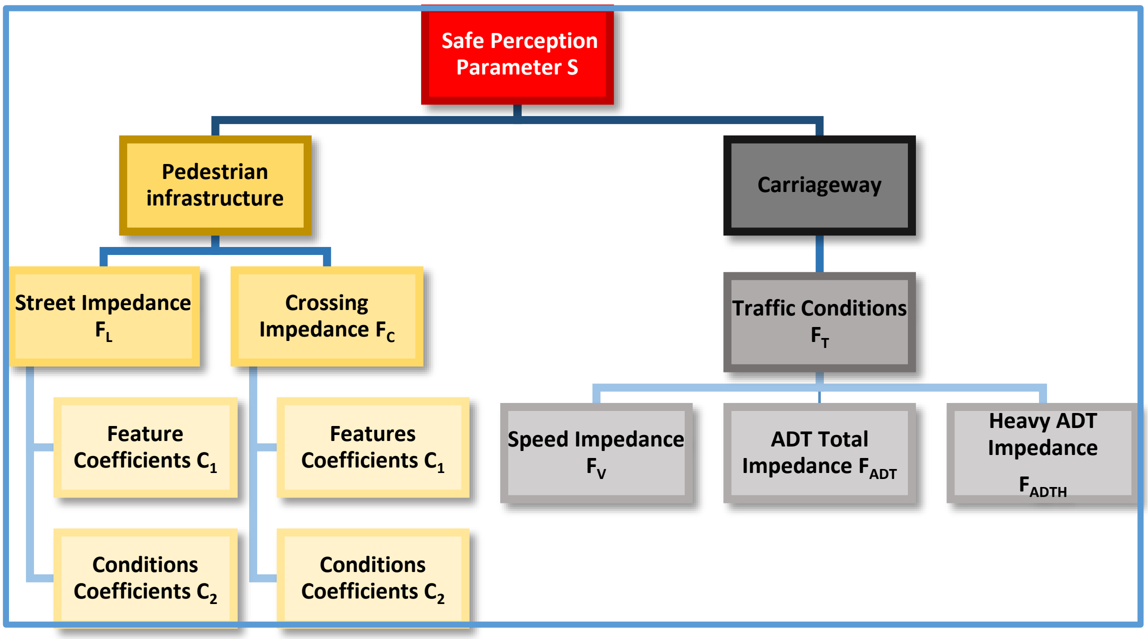
Table 59 – Shared Use Conditions Coefficients

APPENDIX 4B – CROSSING IMPEDANCE METHODOLOGY

Content:

- Crossing Impedance Formulas
- Route Feeling of Insecurity Impedance Index
- Crossing Impedance Index
  - Crossing Impedance
  - Traffic Impedance
- Crossing Impedance Tables
  - C1 coefficients
  - C2 coefficients

1- CROSSING IMPEDANCE FORMULAS



Can be defined as the subjective safe perception while walking along a link or crossing a street. The range of this value goes from 0 (Feeling of security) to 1 (Feeling of insecurity).

2- ROUTE FEELING OF INSECURITY IMPEDANCE INDEX:

Given a route walked by a pedestrian, the total impedance is the sum of all the links and pedestrian crossings that the pedestrian walk along:

$$I_S = \sum I_L + \sum I_C$$

Where:

- I_L = Link impedance
- I_C = Pedestrian crossing impedance

3- CROSSING IMPEDANCE INDEX

For each link, the impedance will be calculated as follows:

$$I_C = \frac{L}{V_w} \times \mathrm{S} = \frac{L}{V_w} \times (C \cdot F_C + \mathrm{B} \cdot F_T)$$

Where:

- I_C = Feeling of Insecurity Impedance Index for a given pedestrian crossing

- L = Length in meters
- V_w = Walking speed
- C, B = Weight coefficients
- F_C = Pedestrian crossing infrastructure impedance
- F_T = Traffic conditions impedance

3.1- Crossing Impedance

This factor refers to the quality of the infrastructure for crossing purposes. Raised crosswalks, marked, are given the best scores while pedestrian crossings without signals are given lower scores.

The rating of FC is from 0 (No impedance) to 1 (High impedance). In order to give a crosswalk a score, the existence of markings, pedestrian phasing, lighting and other factors have been taken into account

$$F_C = \sum f_C = \sum C_1 C_2$$

Where:

- C_1 = Feature coefficient. It weighs the different features crossing a street according to the expert's preference. ***(See section II for tables)***
- C_2 = Condition feature. It gives a score according to the feature's condition. ***(See section II for tables)***

3.2- Traffic Impedance:

$$F_T = D \cdot F_V + E \cdot F_{ADT} + F \cdot F_{ADTH}$$

Where:

- F_V = Vehicle speed impedance
- F_{ADT} = ADT impedance
- F_{ADTH}= Heavy ADT impedance
- D = Speed weight = 0,46
- E = Total ADT weight coefficient = 0,33
- F = Heavy vehicle ADT weight coefficient = 0,21

Speed impedance FV			
Speed (km/h)	Risk of fatality	Risk of severe injured	Adopted index
20	1%	5 %	0,05
30	2 %	10 %	0,1
40	5 %	25 %	0,25
50	10 %	50 %	0,50
60	50 %	65 %	0,65
70	70 %	77 %	0,77
80	90 %	92 %	0,92
90	95 %	97 %	0,97
100	99 %	99 %	0,99
120	100 %	100 %	1.00

Table 60 – Speed Impedance

Traffic Impedance FAADT									
ADT	Root function	Log Function	Root coefficient	Log Coefficient	**ADT Heavy**	Root function	Log Function	Root coefficient	Log Coefficient
1	1,0	0,0	**0,01**	0,00	**1**	1,0	0,00	**0,01**	0,00
10	3,2	1,0	**0,02**	0,23	**5**	2,2	0,70	**0,03**	0,18
20	4,5	1,3	**0,03**	0,30	**10**	3,2	1,00	**0,04**	0,26
50	7,1	1,7	**0,04**	0,39	**15**	3,9	1,18	**0,04**	0,30
100	10,0	2,0	**0,06**	0,45	**20**	4,5	1,30	**0,05**	0,34
150	12,2	2,2	**0,08**	0,49	**40**	6,3	1,60	**0,07**	0,41
200	14,1	2,3	**0,09**	0,52	**50**	7,1	1,70	**0,08**	0,44
300	17,3	2,5	**0,11**	0,56	**75**	8,7	1,88	**0,10**	0,48
400	20,0	2,6	**0,13**	0,59	**100**	10,0	2,00	**0,12**	0,52
500	22,4	2,7	**0,14**	0,61	**150**	12,2	2,18	**0,14**	0,56
750	27,4	2,9	**0,17**	0,65	**200**	14,1	2,30	**0,16**	0,59
1000	31,6	3,0	**0,20**	0,68	**300**	17,3	2,48	**0,20**	0,64
1500	38,7	3,2	**0,24**	0,72	**400**	20,0	2,60	**0,23**	0,67
2000	44,7	3,3	**0,28**	0,75	**500**	22,4	2,70	**0,26**	0,70
3000	54,8	3,5	**0,34**	0,79	**750**	27,4	2,88	**0,32**	0,74
5000	70,7	3,7	**0,44**	0,84	**1000**	31,6	3,00	**0,37**	0,77
7500	86,6	3,9	**0,54**	0,88	**1250**	35,4	3,10	**0,41**	0,80
10000	100,0	4,0	**0,63**	0,91	**1500**	38,7	3,18	**0,45**	0,82
12500	111,8	4,1	**0,70**	0,93	**2500**	50,0	3,40	**0,58**	0,88
15000	122,5	4,2	**0,77**	0,95	**3000**	54,8	3,48	**0,63**	0,90
20000	141,4	4,3	**0,88**	0,98	**4000**	63,2	3,60	**0,73**	0,93
22500	150,0	4,4	**0,94**	0,99	**5000**	70,7	3,70	**0,82**	0,95
25000	158,1	4,4	**0,99**	1,00	**7500**	86,6	3,88	**1,00**	1,00

Table 61 - Traffic Volume Impedance

4- CROSSING IMPEDANCE TABLES

4.1- C1 coefficients

Crossing Coefficients						
	Marking	**Signals**	**Traffic Lights**	**Speed measures**	**Refugee/Island**	**Lighting**
Collector link, or Local link with > 8.000 ADT and Speed Limit 40 – 50 km/h (Large crossings)						
DAY	10%	14%	27%	29%	19%	-
NIGHT	7%	11%	21%	22%	15%	24%
Collector link, or Local link with > 8.000 ADT and Speed Limit 40 – 50 km/h						
DAY	13%	18%	34%	36%	-	-
NIGHT	9%	13%	24%	26%	-	28%
Local link with < 8.000 ADT and Speed Limit 30 – 40 km/h						
DAY	19%	27%	-	54%	-	-
NIGHT	12%	17%	-	34%	-	36%
Residential link with Speed Limit 30 km/h						
DAY	-	-	-	100%	-	-
NIGHT	-	-	-	50%	-	50%

Table 62 - Crossings C1 Table

4.2- C2 coefficients*

Feature Group	Condition	Score	C_2
Signalization	Nothing	*0*	**1**
	Only crosswalk, or children	*50 %*	**0,5**
	Two of them	*100 %*	**0,0**
Marking	No	*0*	**1**
	Yes	*100 %*	**0**
Type of regulation	Nothing	*0*	**1**
	Zebra crosswalk	*50*	**0.5**
	Traffic lights	*100*	**0**
Speed measures type	Nothing	*0 %*	**1**
	Speed limit	*33 %*	**0,66**
	Raised or bump	*66 %*	**0.33**
	Special	*100 %*	**0**
Refugee/Island	No	*0*	**1**
	Yes	*100 %*	**0**
Lighting	No	*0 %*	**1**
	Poor	*50 %*	**0.5**
	Good	*100 %*	**0**

Table 63 - Crossings C2 Table

**If there is a traffic guard or the crossing is a different level than the street or road, F_C is equal to 0.*

APPENDIX 4C – WEB QUESTIONNAIRE

- WEB – QUESTIONARY (NORWEGIAN VERSION)
    - PART ONE: GENERAL QUESTIONS
    - PART TWO: NÅR DU GÅR LANGS GATEN
    - PART THREE: NÅR DU KRYSSER GATEN
    - PART FOUR: OFFENTLIGE VEIER NÆR SKOLER
    - PART FIVE: TRAFIKK NÆR SKOLER

1- WEB – QUESTIONARY (NORWEGIAN VERSION)

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHONOLOGY (NTNU)

Alejandro García-Torres Fernández - Master's Thesis in Traffic Safety

Skolekretsene endres i løpet av planperioden som følge av utbygging og endring av alderssammensetninger i de ulike byområdene. Det kan derfor oppstå nye problemstrekninger og – punkter som følge av at nye skoleveger etableres.

Et kontinuerlig og nært samarbeid med skolen og foreldreutvalg er svært viktig for å få til gode resultater. Flere av skolene har jobbet aktivt med holdningsskapende tiltak overfor elever, lærere og foreldre. Arbeidet med å sikre skolevegen blir aldri helt ferdig og må oppdateres kontinuerlig.

Tid for ferdigstillelse: 5 minutter

1.1- PART ONE: GENERAL QUESTIONS

1.1.1- Hva arbeider du med?

Dersom du studerer/arbeider med noe annet, vennligst velg "Annet" og spesifiser hva du studerer/arbeider med.

a) Student innen bygg- og miljøteknikk

b) Ferdigutdannet/underviser innen bygg- og miljøteknikk

c) Skole lærer/Skole ansatte

d) Annet

1.1.2- Har du barn?

a) Ja

b) Nei

1.1.3- *Har du førerkort?*

a) Ja

b) Nei

"Feeling safe is crucial if we hope to have people embrace city space" *(Jan Gehl, Cities for People)*

¡¡START!!

1.2- PART TWO: NÅR DU GÅR LANGS GATEN

Ranger de følgende elementene etter hvor godt de bidrar til å`unngå ulykker mellom kjøretøy og barn som går langs gaten. (Ikke anser nå gangfelt).

- *1 stjerne = Liten sikkerhet*
- *5 stjerner = Utmerket sikkerhet*

1.2.1- Grønne/beplantede områder som skiller fortau og vegbane.

1.2.2- Fortau for fotgjengere

1.2.3- <u>*Sikkerhetsbarrierer*</u>

1.2.4- <u>*Sykkelfelt mellom fortauet og vegbanen* ***(Sykler regnes ikke biler)***</u>

1.2.5- Parkeringsområde mellom vegbane og fortau

1.2.6- Vegskuldre

1.2.7- *Skilt som indikerer barnene pa gaten*

1.2.8- *Gatelys*

1.3- PART THREE: NÅR DU KRYSSER GATEN

Ranger de følgende elementene etter hvor godt de bidrar til å`unngå ulykker mellom kjøretøy og barn som krysser gaten.

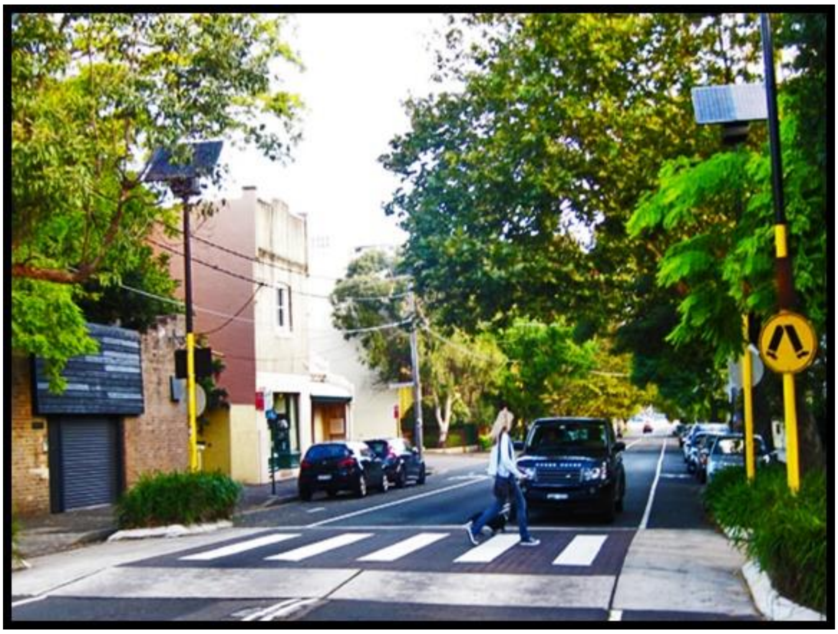
- *1 stjerne = Liten sikkerhet*
- *5 stjerner = Utmerket sikkerhet*

1.3.1- Gangfelt med trafikkvakt

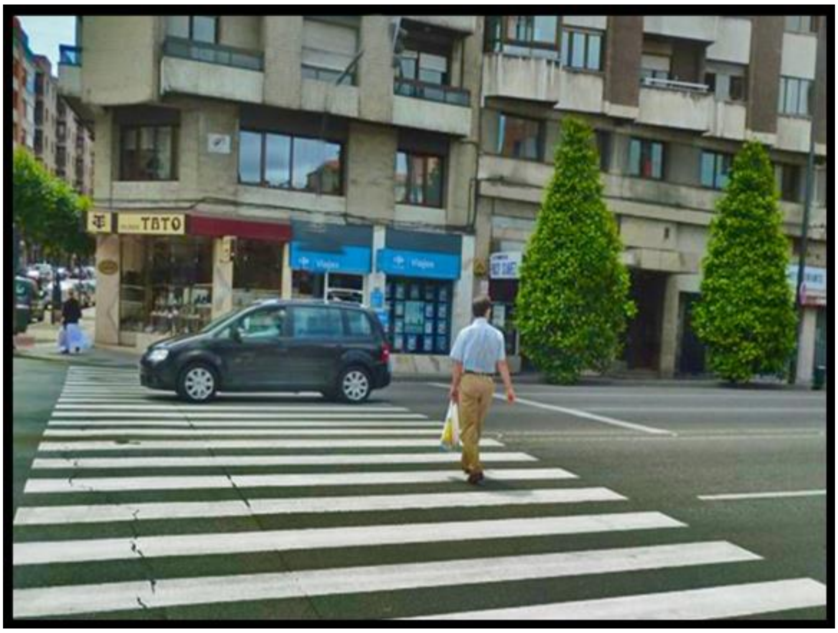
1.3.2- Underganger/overganger som skiller fotgjengerne fra trafikken

1.3.3- *Gangfelt med lysregulering*

1.3.4- *Opphøyede gangfelt (Uten lysregulering)*



1.3.5- <u>Gangfelt (Uten lysregulering)</u>



1.3.6- <u>Skilt som indikerer gangfelt</u>

1.3.7- Midtrabatter ved lange krysninger

1.3.8- Fartsreduserende tiltak

1.3.9- *Belysning av gangfelt*

1.4- PART FOUR: OFFENTLIGE VEIER NÆR SKOLER

Ranger de følgende elementer etter faren de utgjør for barn som benytter offentlige veier nær skoler

1.4.1- *Hva mener du utgjør **MEST FARE?***

1.4.2- *Hva mener du utgjør **NEST MEST FARE?***

1.4.3- *Hva mener du utgjør **MEST FARE?***

1.4.4- *Hva mener du utgjør **NEST MEST FARE?***

1.5- PART FIVE: TRAFIKK NÆR SKOLER

Ranger de følgende elementer etter faren de utgjør for barn nar har trafikk nær skoler.

- *1 stjerne = No effect*
- *5 stjerner = Very possitive*

1.5.1- Fjerne parkering på gaten

1.5.2- Prohibing trafikkflyt ved skolen inngangen

1.5.3- Forbedre vegoppmerking rundt skolene

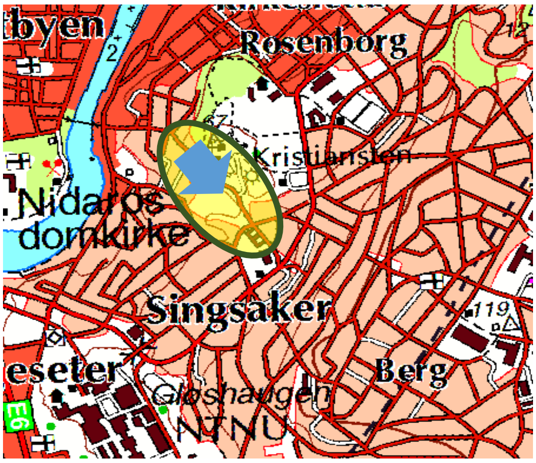
1.5.4- Plassere trafikkvakter på skoleoverganger

1.5.5- *Bedre gangfelt synlighet*

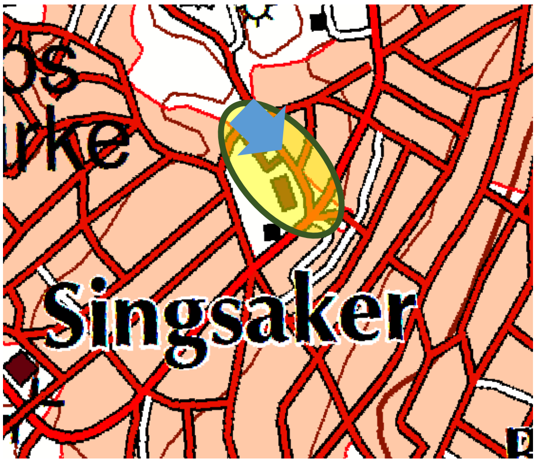
1.5.6- *Redusere fartsgrensen rundt skoler*

APPENDIX 5A – 5M – COUNTERMEASURES

- Appendix 5A – Kristianstensbakken
- Appendix 5B – Rogers Gate
- Appendix 5C – Schmidts Gate
- Appendix 5D – Eidsvoll Gate
- Appendix 5E – Eidsvoll Gate
- Appendix 5F – Eidsvoll Gate
- Appendix 5G – Eidsvoll Gate
- Appendix 5H – Ovre Alle
- Appendix 5I – Nedre Alle
- Appendix 5J – Klaebuveien
- Appendix 5K – Jonsvannsveien
- Appendix 5L – Tyholtveien
- Appendix 5M – Strindvegen

APPENDIX 5A	
Suggested Countermeasures	-Build a 2m sidewalk on one side. -*Set 20 km/h speed limit** / Ensure low speed limit <30 km/h. -Children sign (Nº142).
Location	
	
Street Name	Kristianstensbakken
Problem description	This is a street included in frequently walked routes to school which has been found without a sidewalk and a speed limit of 30 km/h.
Objectives	Since this street is very close to the school zone we suggest building a 2 meter width sidewalk on the side closest to the hill, setting the speed limit at 20 km/h* (ensuring low speed limit), and installing a children sign Nº142.
Cost	Low cost measure

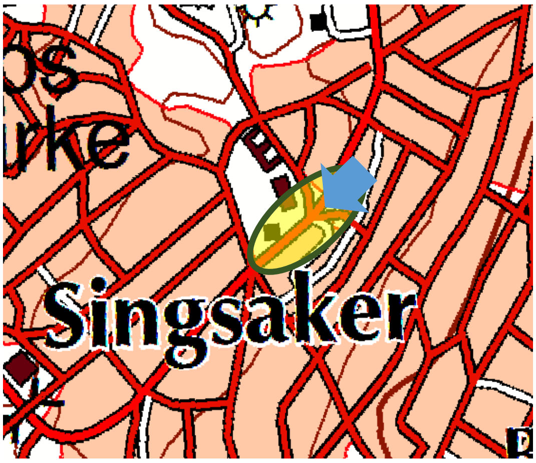
**The minimum speed limit in Norway is 30 km/h for all public roads*

APPENDIX 5B	
Countermeasures	-Build a 2m sidewalk on one side. -*Set 20 km/h speed limit** / Ensure low speed limit <30 km/h. -Children sign (Nº142).
Location	
	
Street Name	Rogers Gate
Problem description	This street is within the school zone and it is also frequently walked by children. Sidewalk on the left side is very narrow while on the right side there is no sidewalk at all. The speed limit is 30 km/h.
Objectives	Since this street is very close to the school zone we suggest building a 2 metre width sidewalk on the side closest to the hill, setting the speed limit at 20 km/h* (ensuring a low speed limit), and installing a children sign Nº142.
Cost	Low cost measure

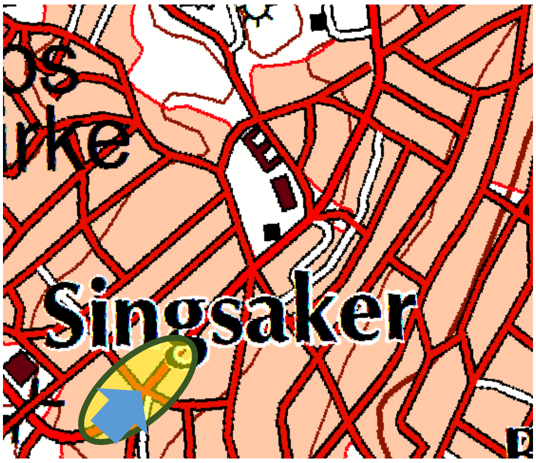
**The minimum speed limit in Norway is 30 km/h for all public roads*

APPENDIX 5C	
Countermeasures	-*Set 20 km/h speed limit* /* Ensure low speed limit <30 km/h. -Children sign (N°142).
Location	
	
Street Name	Schmidts Gate
Problem description	This street is so narrow that it has been classified as “Shared use street”. The speed limit is 30 km/h.
Objectives	Since this street is very close to the school zone we suggest setting the speed limit at 20 km/h* (ensuring a low speed limit), and installing a children sign N°142
Cost	Low cost measure

**The minimum speed limit in Norway is 30 km/h for all public roads*

APPENDIX 5D	
Countermeasures	-Raise pedestrian crossing -*Colored pavement at crossings with white marks* * / Markings maintenance
Location	
	
Street Name	Eidsvoll Gate
Problem description	This pedestrian crossing is one of the closest to Singsaker School and it has been found to be unraised and poorly marked.
Objectives	Since this pedestrian crossing is within the school zone we suggest raising it, installing a *coloured pavement at crossings with white marks** in order to improve visibility, ensuring marking maintenance and installing a children sign.
Cost	Low cost measure

**Colored pavement at pedestrians crossing with white marks are not included in Norwegian Legislation*

APPENDIX 5E	
Countermeasures	-Raise pedestrian crossing -*Colored pavement at crossings with white marks* * / Markings maintenance -Children sign (Nª142)
Location	
	
Street Name	Eidsvoll Gate
Problem description	This pedestrian crossing is included in key routes to Singsaker School and it has been found to be marked but not well maintained.
Objectives	Since this pedestrian crossing is within the school zone we suggest raising it up and installing a *colored pavement at crossings with white marks** in order to improve visibility, ensuring marking maintenance and installing a children sign.
Cost	Low cost measures

**Colored pavement at pedestrians crossing with white marks are not included in Norwegian Legislation*

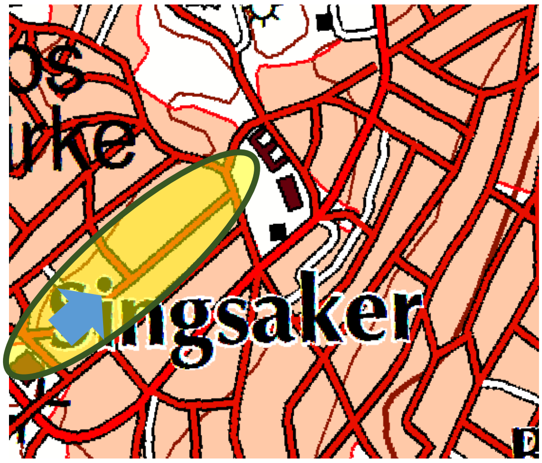
<table>
<tr><th colspan="2">APPENDIX 5F</th></tr>
<tr><td>Countermeasures</td><td>-Adult School Crossing Guards.</td></tr>
<tr><td colspan="2">Location</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Street Name</td><td>Eidsvoll Gate</td></tr>
<tr><td>Problem description</td><td>This is the major intersection in Singsaker Neighborhood, one of the closest to the school, and it is regulated with traffic lights. However, at peak hours (school opening and closing time) it could become a busy intersection.</td></tr>
<tr><td>Objectives</td><td>Adult volunteers are key elements at busy intersections for helping children to cross the street.</td></tr>
<tr><td>Cost</td><td>Low cost measure</td></tr>
</table>

APPENDIX 5G	
Countermeasures	-Raise pedestrian crossing -*Colored pavement at crossings with white marks* * / Markings maintenance
Location	
	
Street Name	Eidsvoll Gate
Problem description	This pedestrian crossing is included in the key routes to Singsaker School and it has been found marked but not well maintained.
Objectives	Since this pedestrian crossing is within the school zone we suggest raising it up, installing a *colored pavement at crossings with white marks** in order to improve visibility, ensuring marking maintenance and installing a children sign.
Cost	Low cost measure

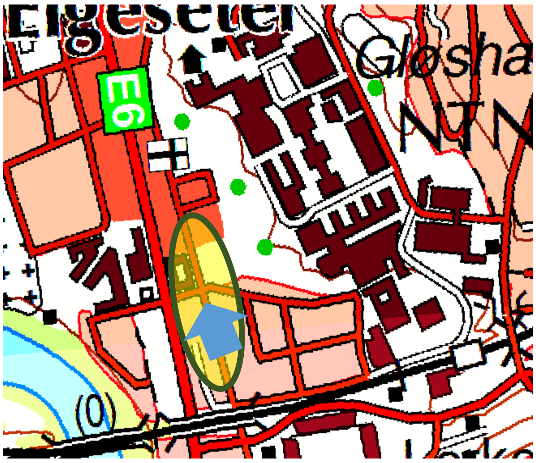
**Colored pavement at pedestrians crossing with white marks are not included in Norwegian Legislation*

APPENDIX 5H	
Countermeasures	-*Set 20 km/h speed limit** / Ensure low speed limit <30 km/h -Children sign (Nº142)
Location	
	
Street Name	Ovre Alle
Problem description	This is a street included in frequently walked routes to school which has been found with a speed limit of 30 km/h.
Objectives	Since this streets is very close to the school zone we suggest setting the speed limit at 20 km/h* (ensuring a low speed limit), and installing a children sign Nº142.
Cost	Low cost measure

**The minimum speed limit in Norway is 30 km/h for all public roads*

APPENDIX 5I	
Countermeasures	-Build a 2m sidewalk on one side -*Set 20 km/h speed limit* / Ensure low speed limit <30 km/h -Children sign (Nº142)
Location	
	
Street Name	Nedre Alle
Problem description	This is a street included in the frequently walked routes to school which has been found without a sidewalk and a speed limit of 30 km/h.
Objectives	Since this street is very close to the school zone we suggest building a 2 meter width sidewalk on the left side, ensuring a low speed limit, and installing a children sign.
Cost	Low cost measure

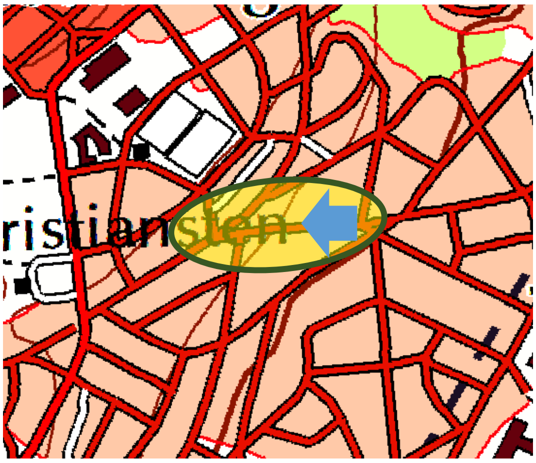
**The minimum speed limit in Norway is 30 km/h for all public roads*

APPENDIX 5J	
Countermeasures	-Raise pedestrian crossing. -*Colored pavement at crossings with white marks* * / Markings maintenance.
Location	
	
Street Name	Klaebuveien
Problem description	This pedestrian crossing is included in the key routes to school and is unraised.
Objectives	Since this pedestrian crossing is within the school zone we suggest raising it, installing a *colored pavement at crossings with white marks** in order to improve visibility, and ensuring marking maintenance.
Cost	Low cost measure

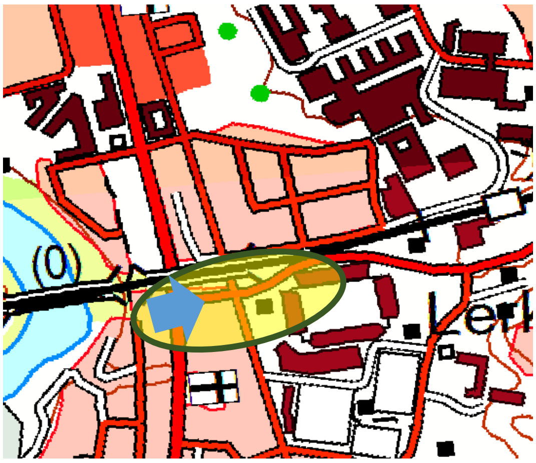
**Colored pavement at pedestrians crossing with white marks are not included in Norwegian Legislation*

APPENDIX 5K	
Countermeasures	-Raise pedestrian crossing. -*Colored pavement at crossings with white marks* * / Markings maintenance.
Location	
	
Street Name	Jonsvannsveien
Problem description	This pedestrian crossing is just beside the entrance to Singsaker School and it is unraised and poorly marked.
Objectives	Since this pedestrian crossing is within the school zone we suggest raising it and installing *colored pavements at crossings with white marks** in order to improve visibility, and ensure marking maintenance.
Cost	Low cost measure

**Colored pavement at pedestrians crossing with white marks are not included in Norwegian Legislation*

APPENDIX 5L	
Countermeasures	-Build a 2m sidewalk on one side. -*Set 20 km/h speed limit* / Ensure low speed limit <30 km/h.
Location	
	
Street Name	Tyholtveien
Problem description	This is a street included in frequently walked routes to school which has been found with a very narrow sidewalk and a speed limit of 30 km/h.
Objectives	Since this street is very close to the school zone we suggest building a 2 meter width sidewalk on the side closest to the hill and setting the speed limit at 20 km/h* (ensuring a low speed limit).
Cost	Low cost measure

**The minimum speed limit in Norway is 30 km/h for all public roads*

APPENDIX 5M	
Countermeasures	-Install refugee island
Location	
	
Street Name	Strindvegen
Problem description	This pedestrian crossing is included in key routes to school and it is a large one. Although lanes are separated by a median, there is no refuge island for pedestrians, and the speed limit is 50 km/h.
Objectives	Since it is included in the key routes to school we suggest installing a refuge island.
Cost	Low cost measure

MAP SET APPENDIX

MAP SET APPENDIX

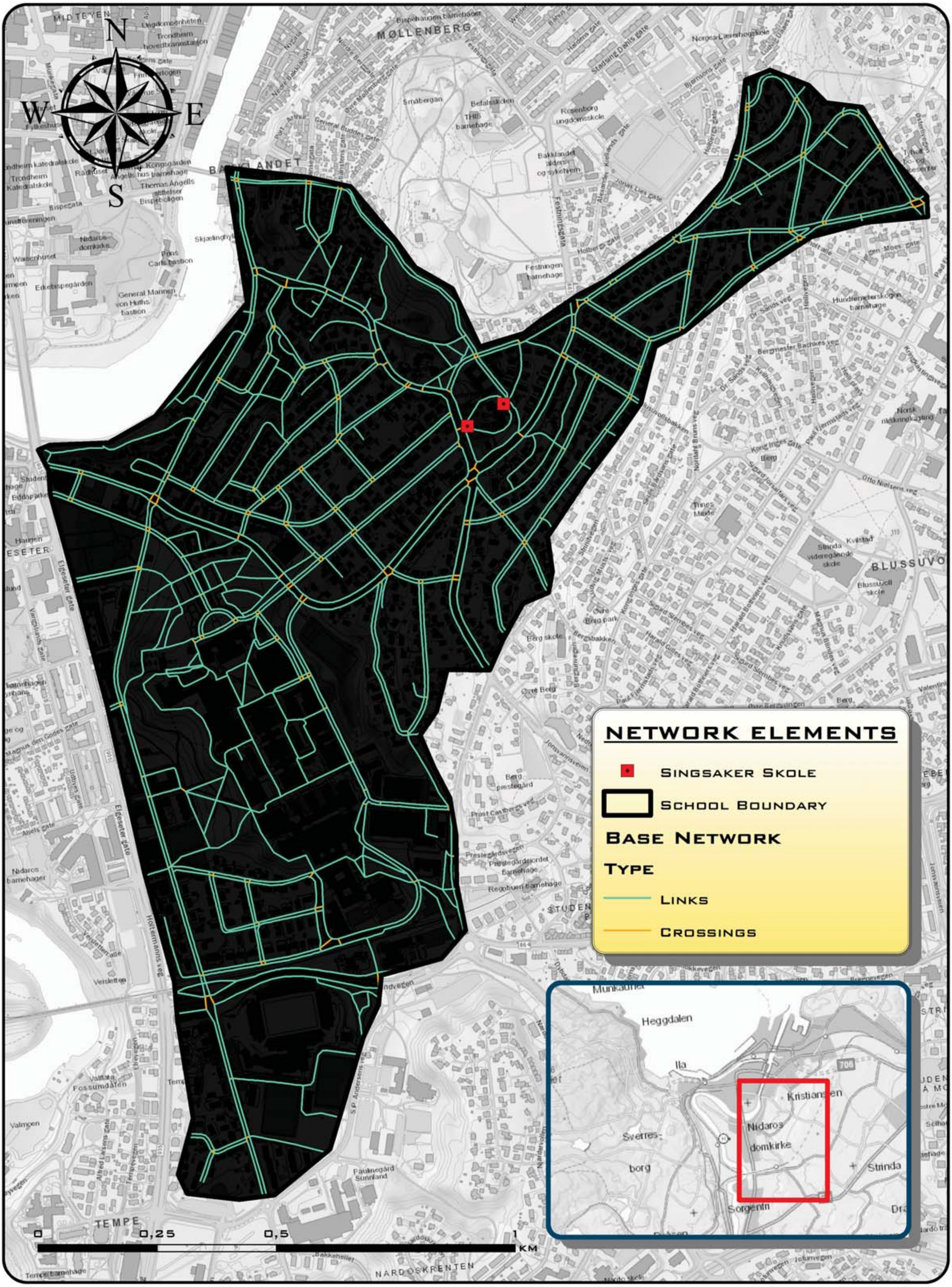
First of all, it must be mentioned that this document contains many figures, tables and maps to facilitate the reader's understanding during the reading and evaluation process.

Of particular mention are the maps included in the ***Map Set Appendix***, which are intended to be printed on A3 format paper to better appreciate the details. Therefore, when reading and evaluating the document it is recommended to have a copy of this appendix at hand so that the maps be visualized in a much higher and more detailed resolution: otherwise, small details might not be appreciated in depth.

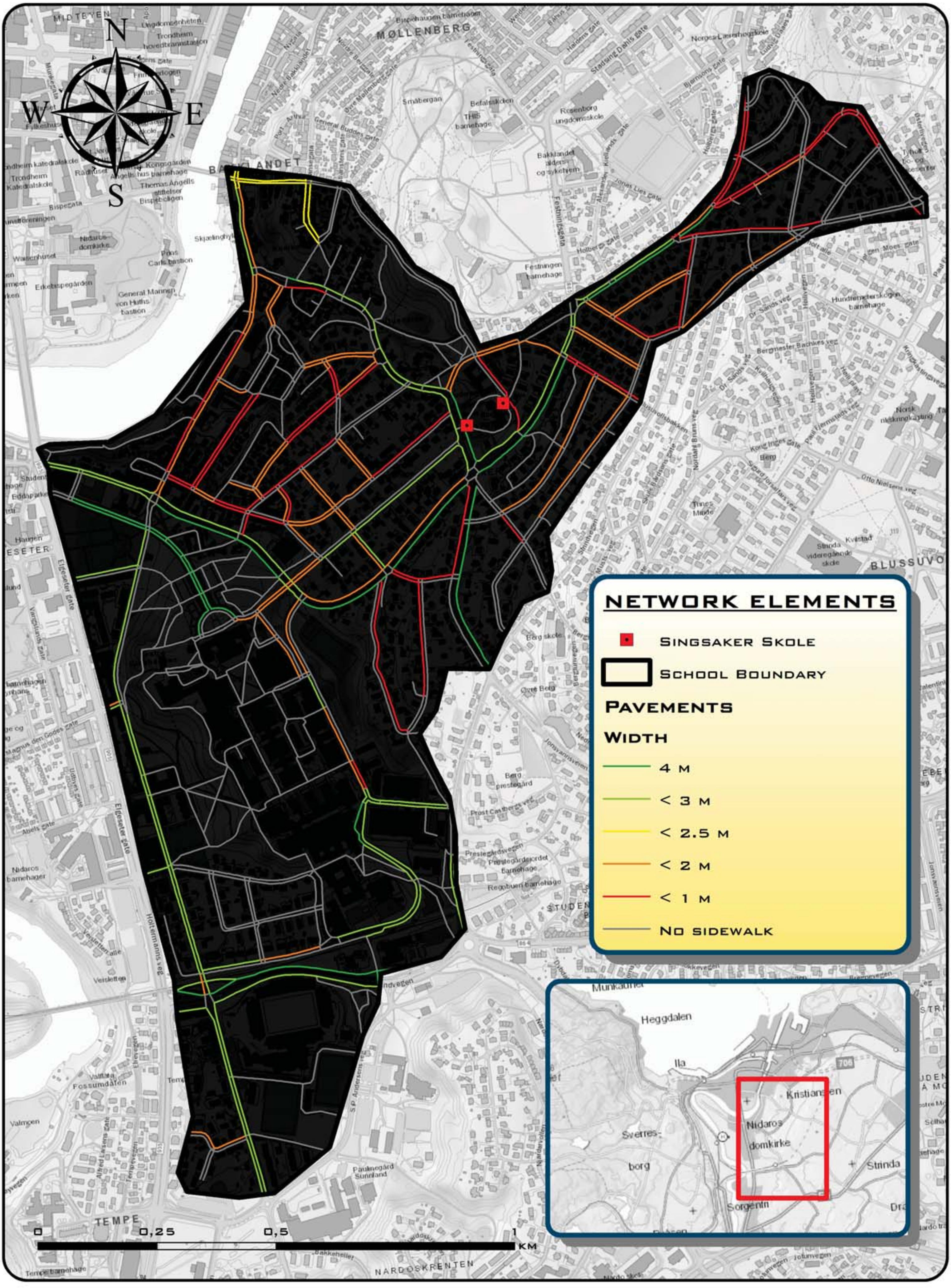
- Map set Appendix 3A – Base Network
- Map set Appendix 3B - Pavements
- Map set Appendix 3B-2 – Buffers and Barriers
- Map set Appendix 3C – Parking Lanes
- Map set Appendix 3D – Bike Lanes
- Map set Appendix 3E - Signalization
- Map set Appendix 3F – Crossing Facilities
- Map set Appendix 3G – Speed Limit
- Map set Appendix 3H – Traffic Volume
- Map set Appendix 3I – Feeling of Insecurity
- Map set Appendix 3J – Singsaker Children's Routes
- Map set Appendix 3K – Singsaker School Report
- Map set Appendix 5A – School Selection
- Map set Appendix 5B – Accessibility (Walking Time)
- Map set Appendix 5C – Accessibility (Insecurity Time)
- Map set Appendix 5D – Shortest Corridors
- Map set Appendix 5E – Lowest Insecurity Corridors
- Map set Appendix 5F – Building Distribution
- Map set Appendix 5G – Street Hierarchy
- Map set Appendix 5H - Accessibility (Countermeasures)

Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department

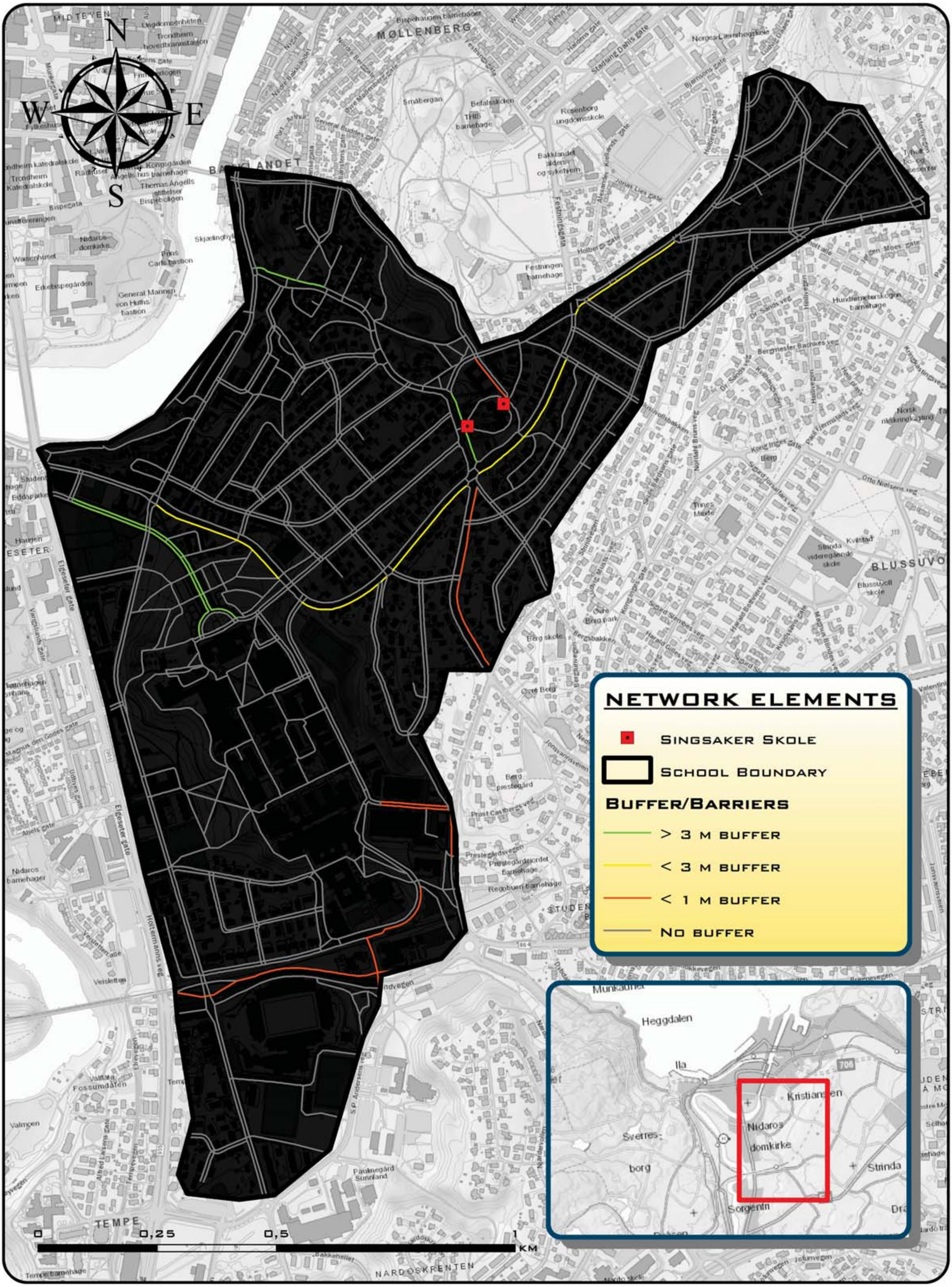
Code	Author	Map Set Appendix	Location	Year
3 A	Alejandro Garcia-Torres F.	Base Street Network	Trondheim, Norway	2017



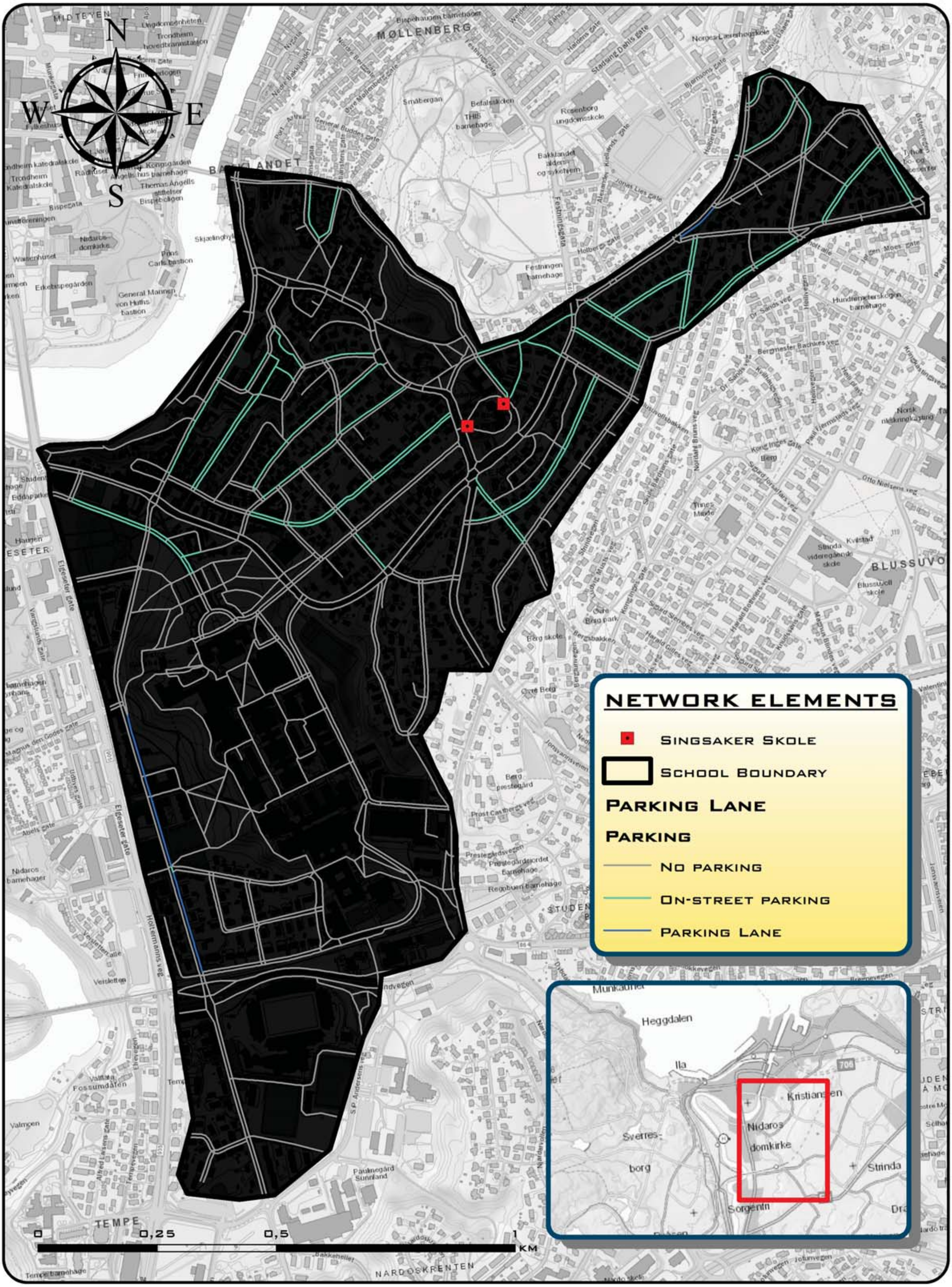
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 B	Alejandro Garcia-Torres F.	Pavements	Trondheim, Norway	2017



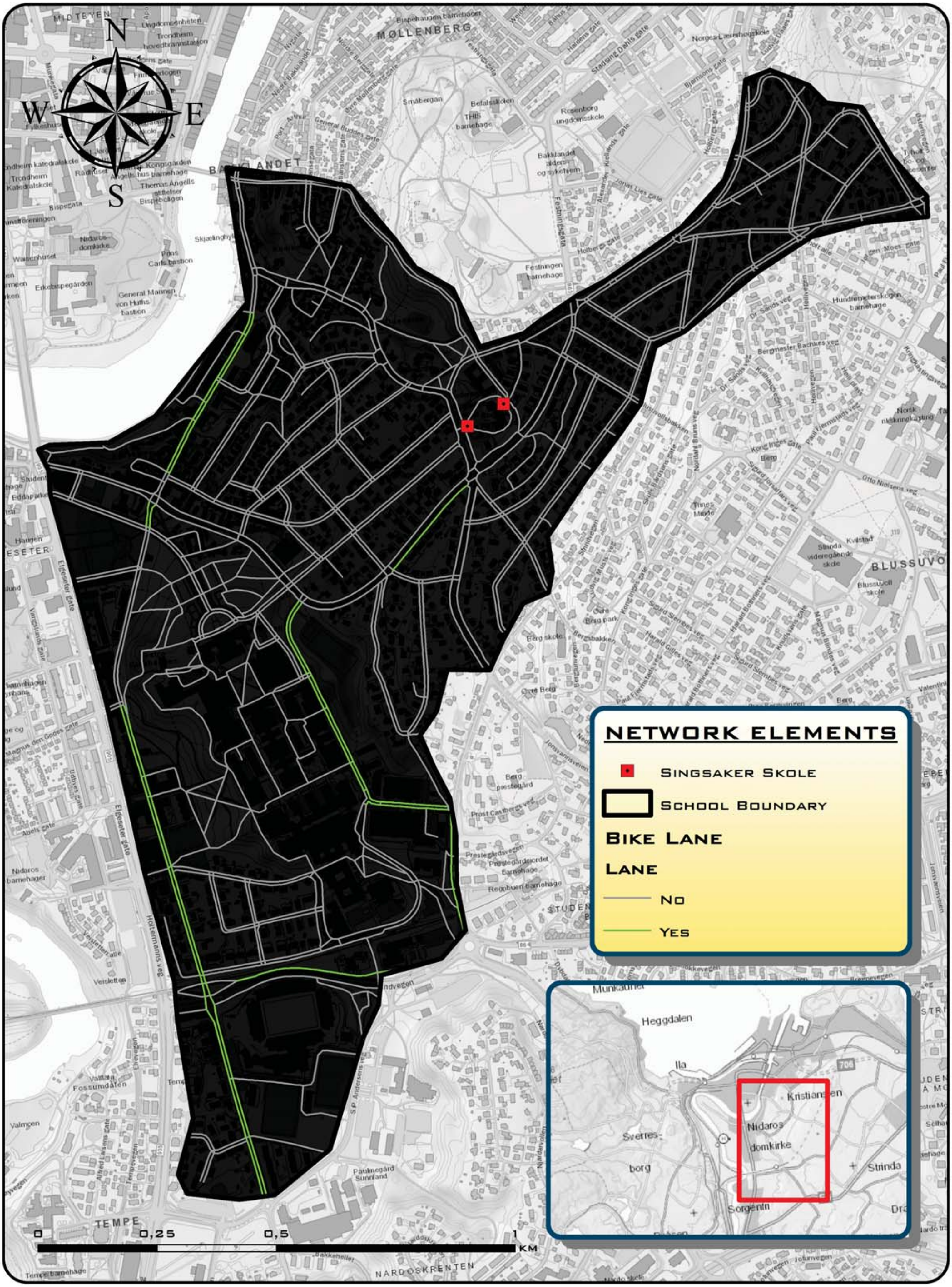
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 B-2	Alejandro Garcia-Torres F.	Buffers and Barriers	Trondheim, Norway	2017



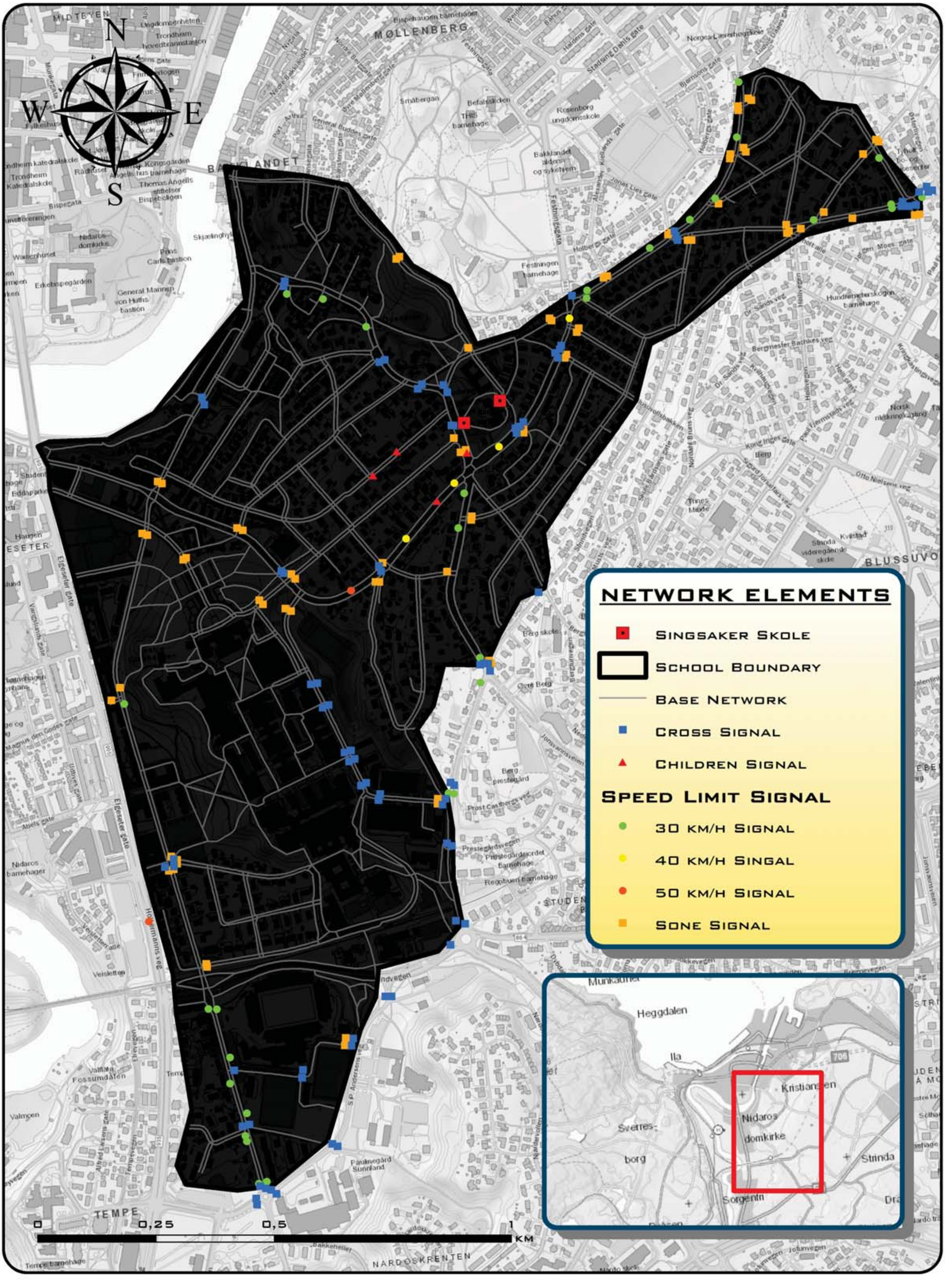
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 C	Alejandro Garcia-Torres F.	On-Street Parking / Parking Lane	Trondheim, Norway	2017



Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 D	Alejandro Garcia-Torres F.	Bike Lane	Trondheim, Norway	2017

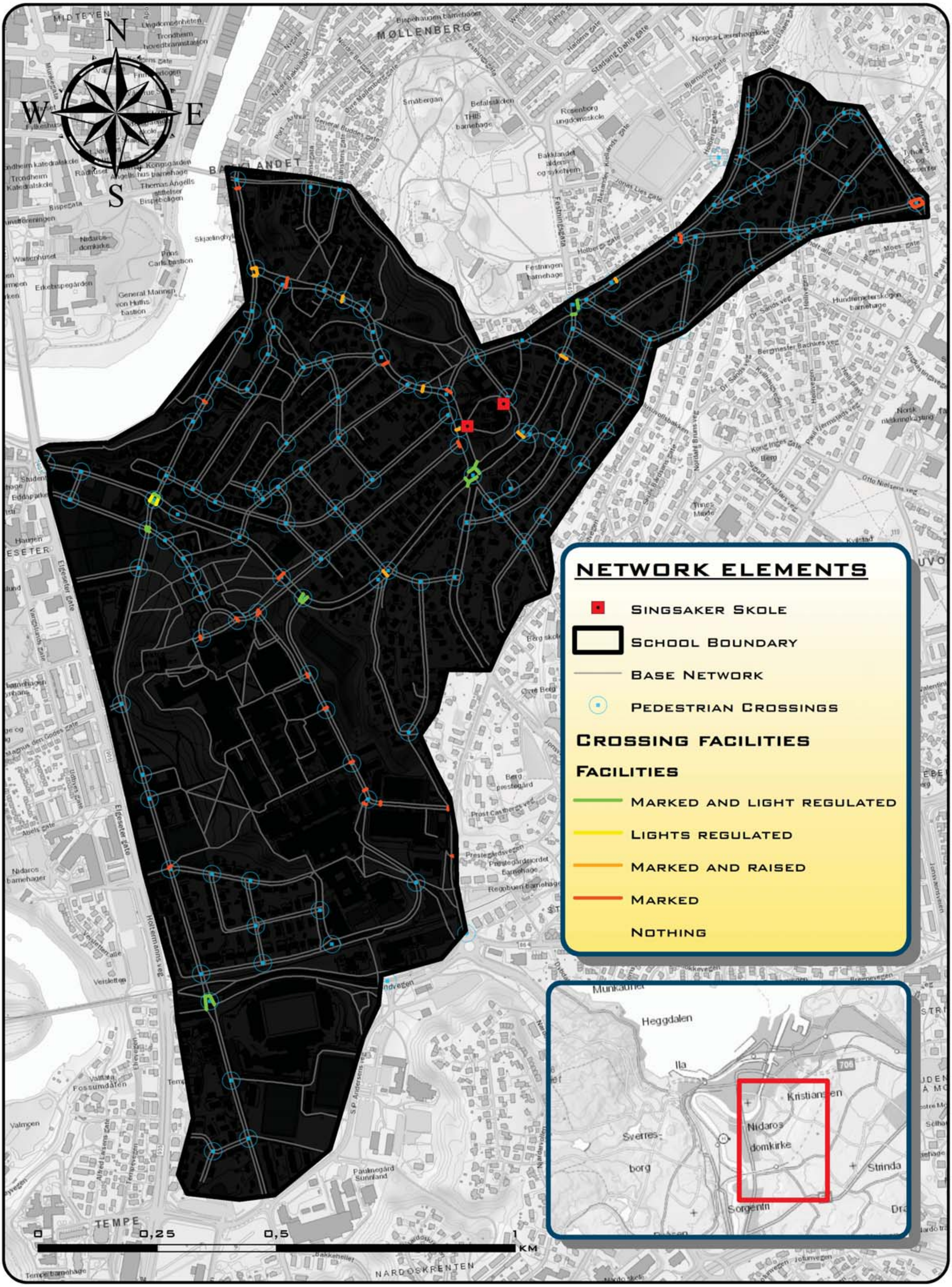


Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 E	Alejandro Garcia-Torres F.	Signalization	Trondheim, Norway	2017

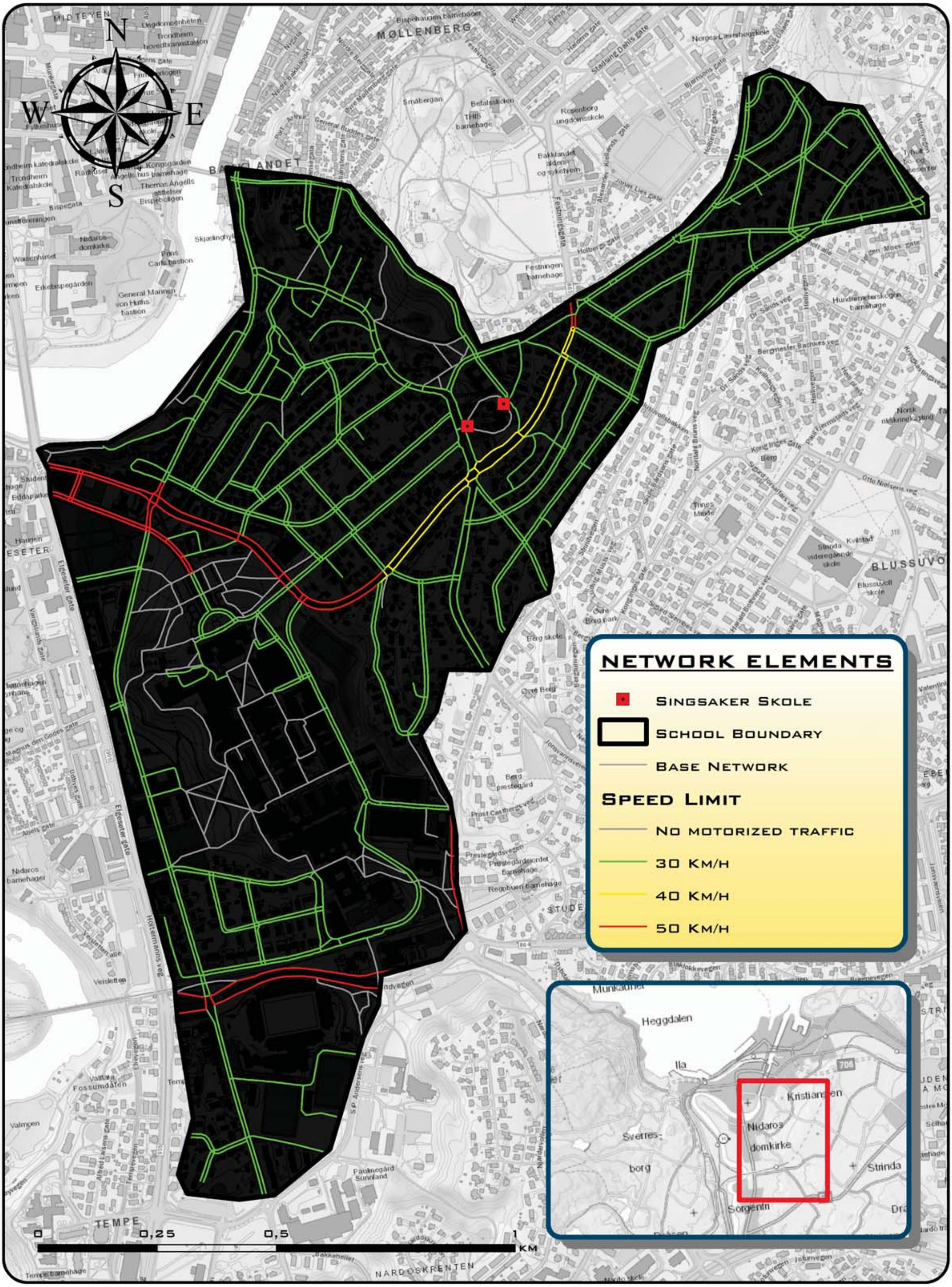


Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department

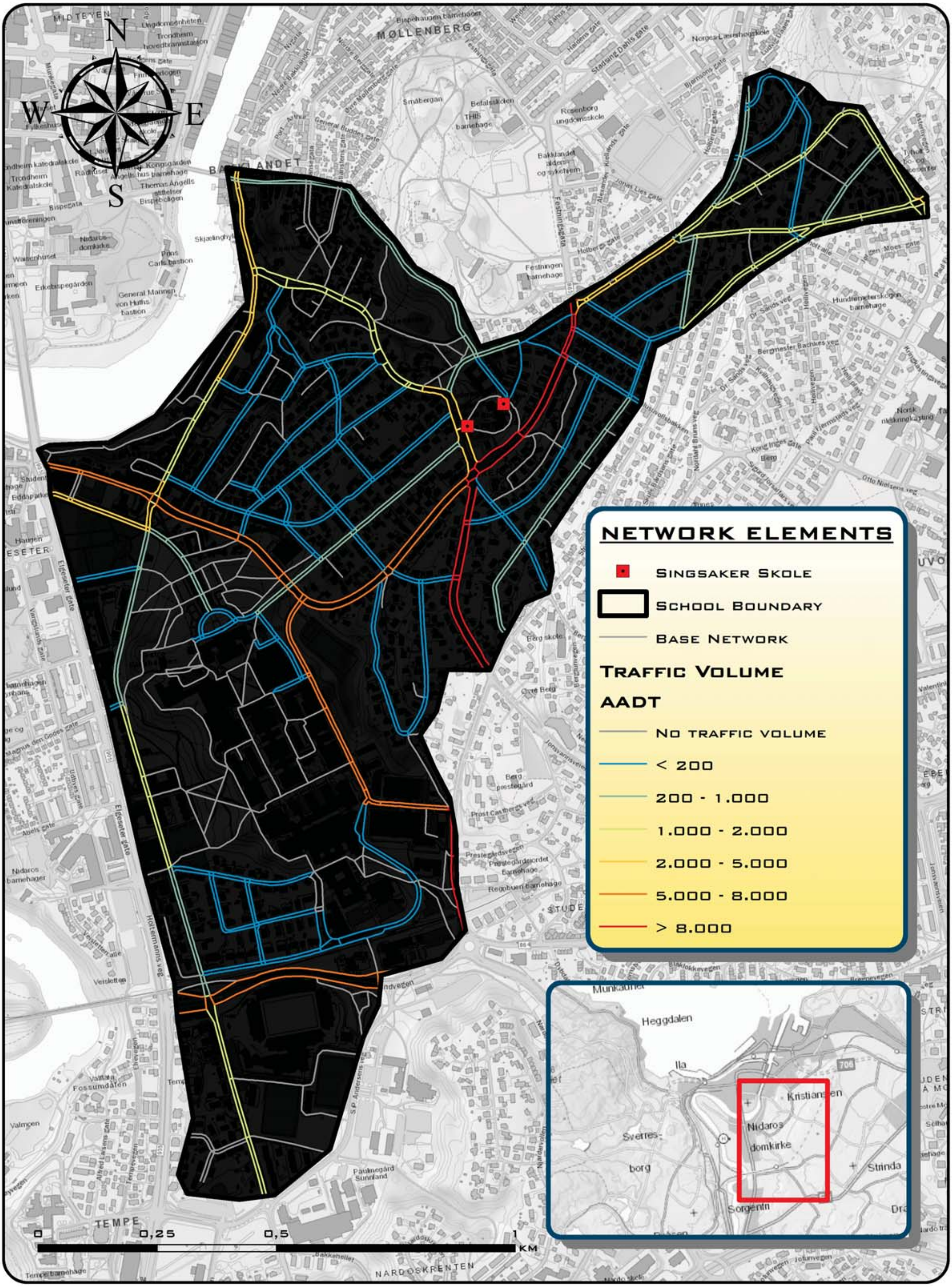
Code	Author	Map Set Appendix	Location	Year
3 F	Alejandro Garcia-Torres F.	Crossing Facilities	Trondheim, Norway	2017



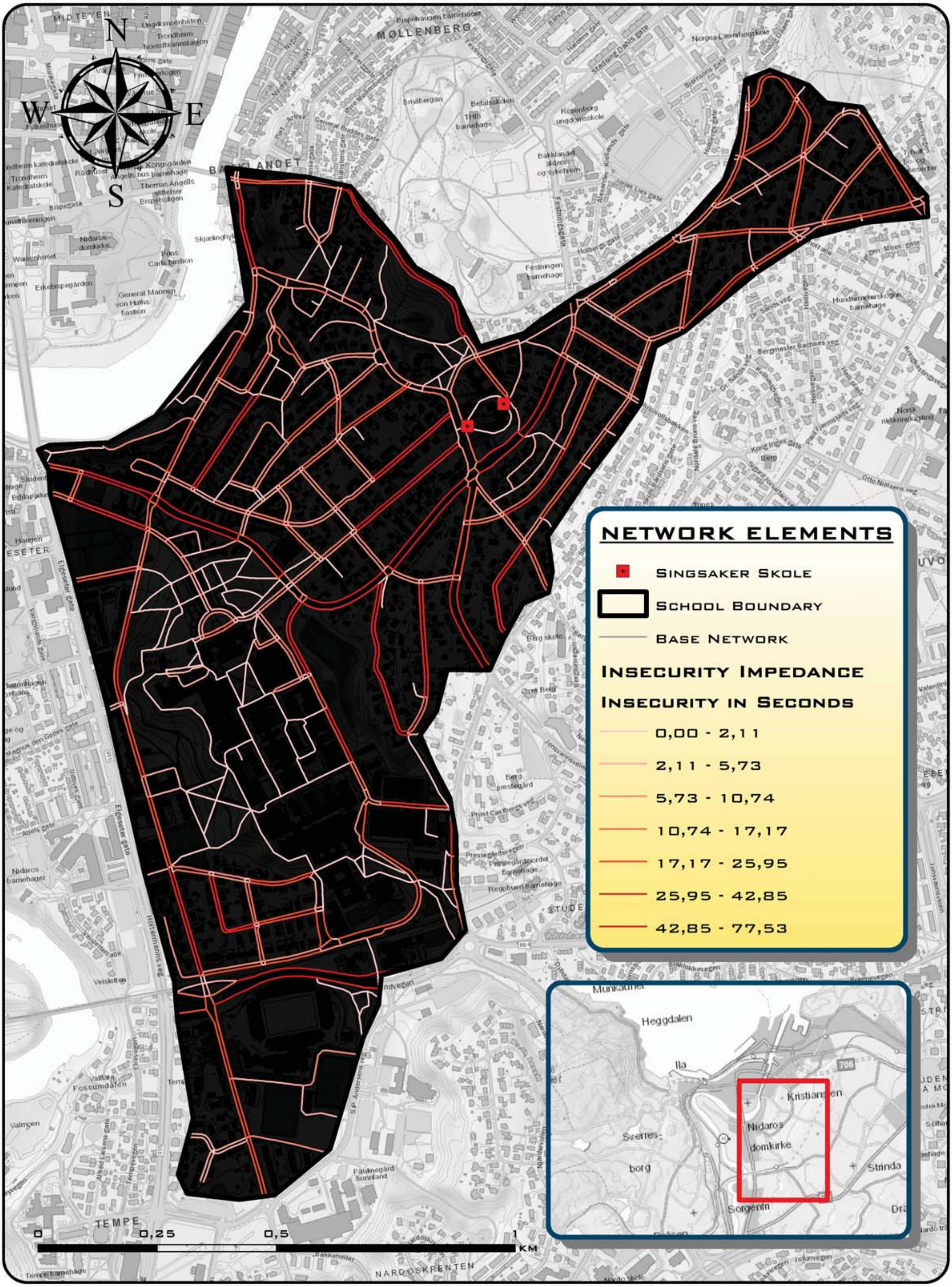
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 G	Alejandro Garcia-Torres F.	Speed Limit	Trondheim, Norway	2017



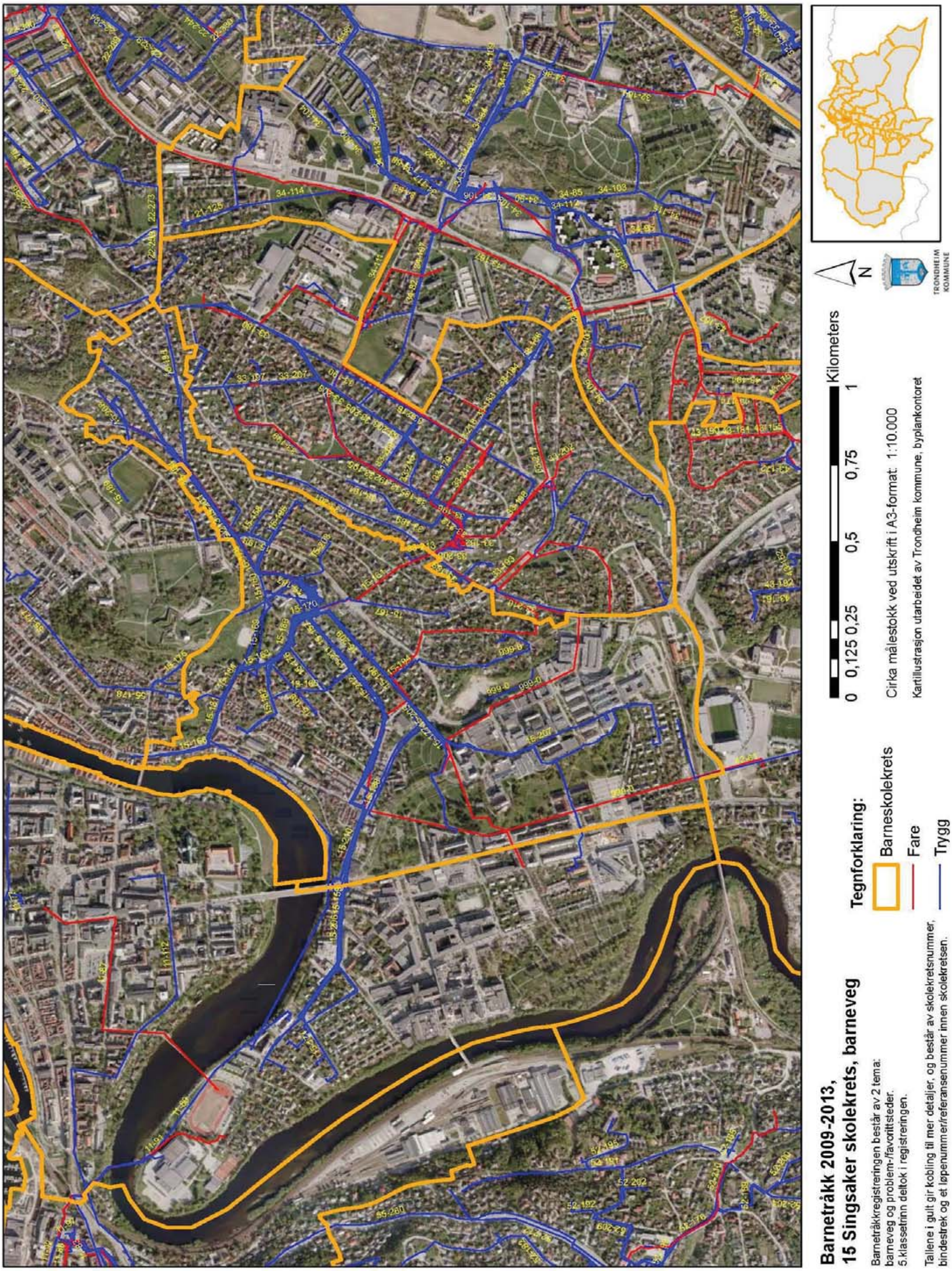
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 H	Alejandro Garcia-Torres F.	Traffic Volume	Trondheim, Norway	2017

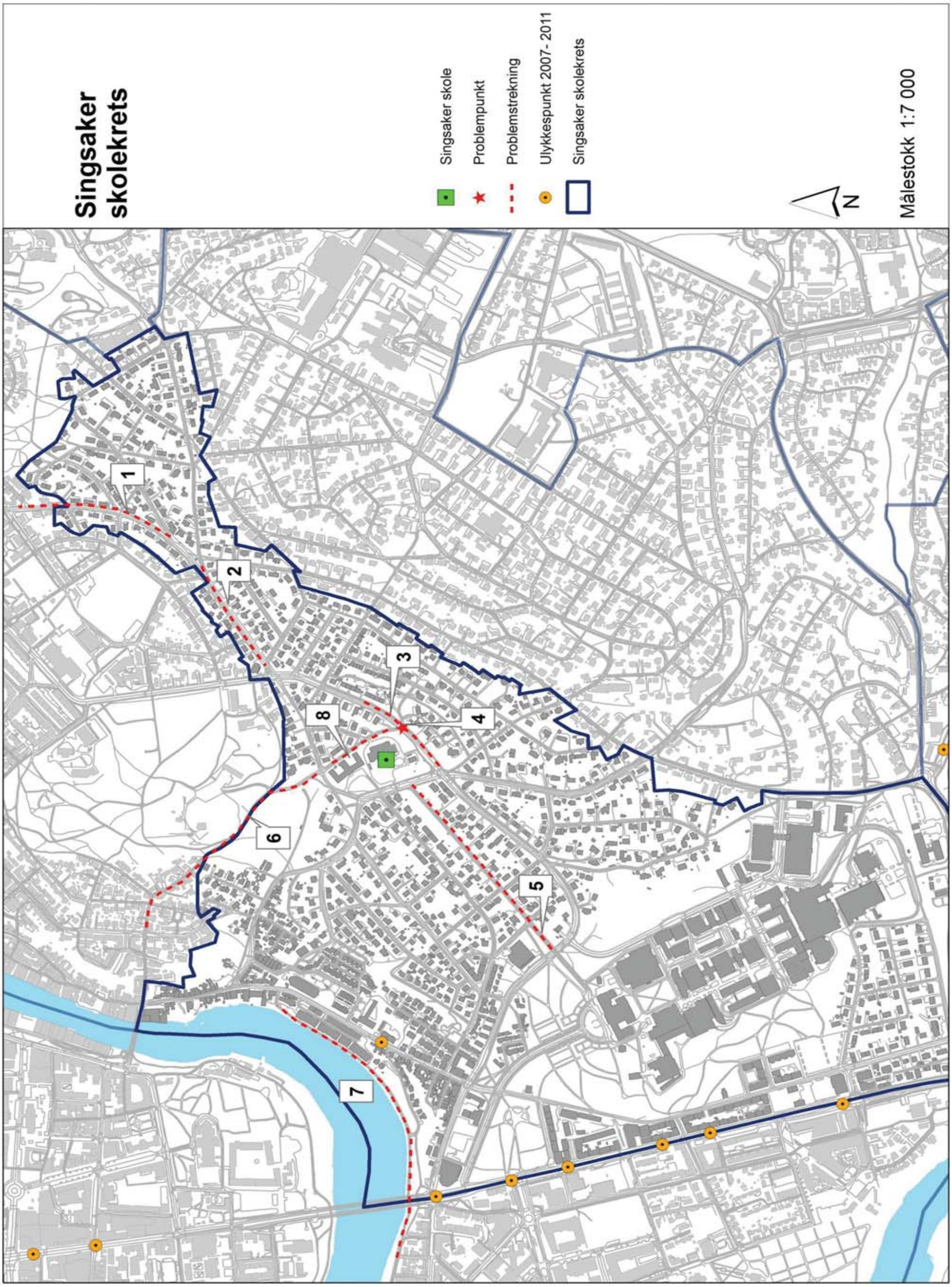


Code	Author	Map Set Appendix	Location	Year
31	Alejandro Garcia-Torres F.	Feeling of Insecurity	Trondheim, Norway	2017



Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
3 J	Alejandro Garcia-Torres F.	Singsaker Children's Route	Trondheim, Norway	2017





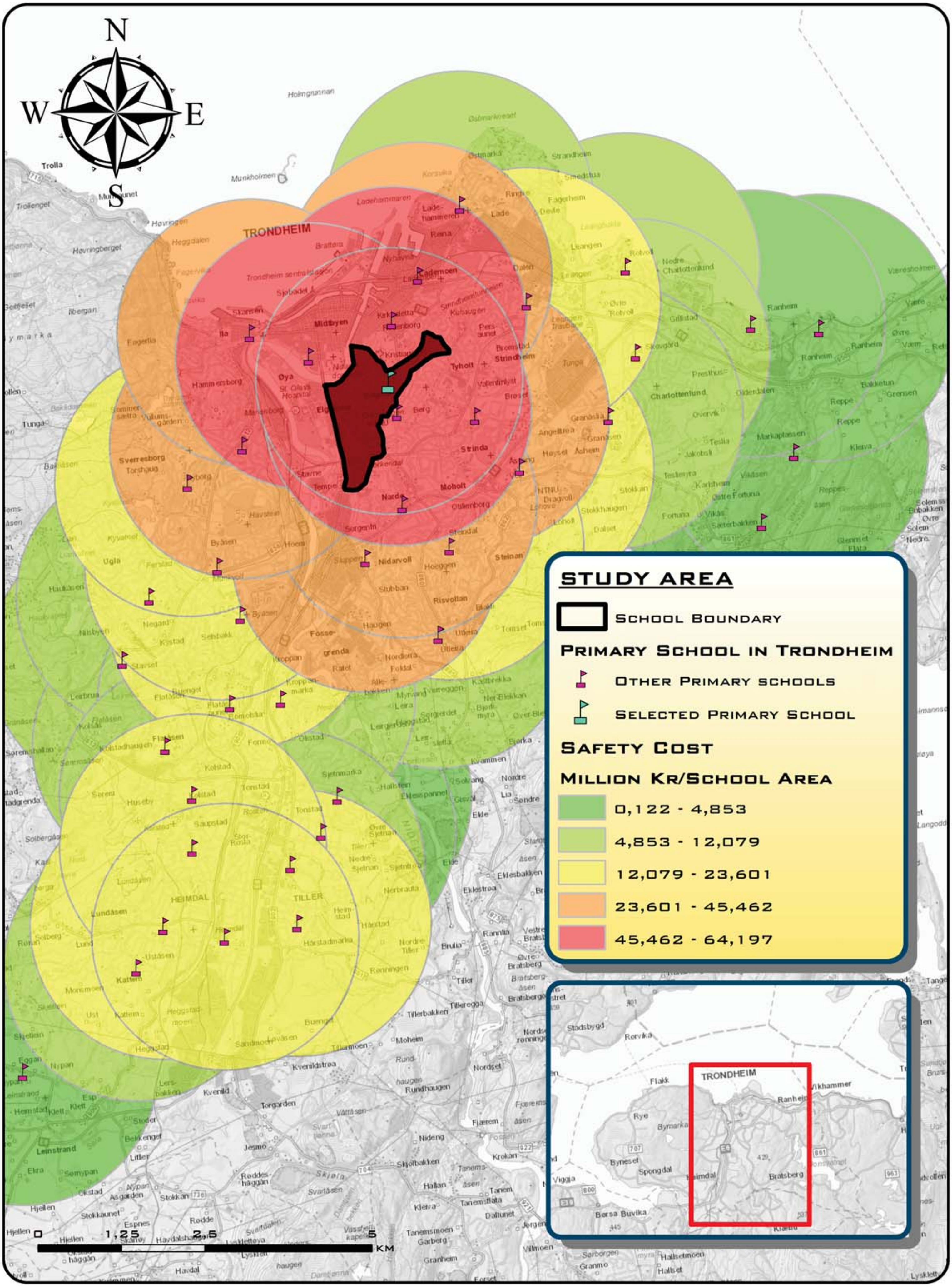
Singsaker skolekrets
Singsaker skole
Problempunkt
Problemstrekning
Ulykkespunkt 2007- 2011
Singsaker skolekrets
N
Målestokk 1:7 000
1
2
3
4
5
6
7
8

Singsaker skolekrets

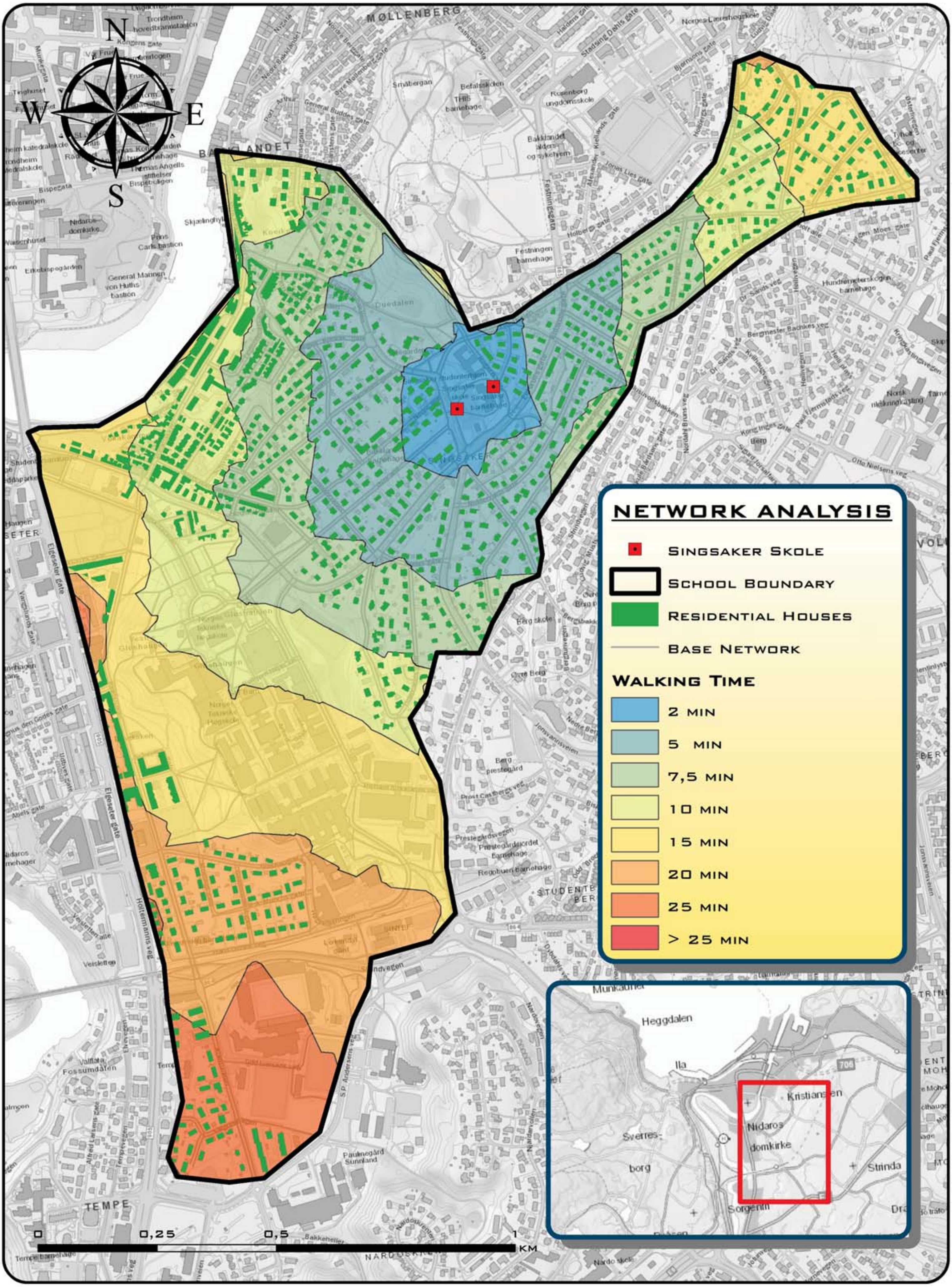
Skolens kontaktperson:	Telefon:	Definisjoner:
Rektor Gunn Langseth Trøan	73 88 40 40	TK = Trondheim kommune; SVV = Statens vegvesen; STFK = Sør-Trøndelag fylkeskommune

	Opplevde trafikkfarlige områder	Problem	Forslag/kommentar	Ansvarlig
1	Henrik Mathisens veg	Smalt fortau, høyt fartsnivå og busstrase.	Vurdere utvidelse av fortau innen eksisterende vegareal eller med regulering	TK
2	Strekning langs Tyholtvegen	Høyt fartsnivå, ønsker heltrukne fartsdempere og innsnevring av vegbane. Ønsker opphøyd fotgjengerovergang ved kryss Asbjørnsens gate. Mangler fortau fra Aleksander Kiellands gate til Festningsgata. Siktrydding nødvendig i flere kryss pga forvokst vegetasjon.	Vurdere tiltak i sammenheng med praksis for fartsdemping i kollektivtrase. Vurdere utbedringer i forbindelse med reguleringsplan Tyholtvegen/ Asbjørnsens gate	TK/private grunneiere
3	Eidsvolls gate forbi skolen	Høyt fartsnivå, 50 km/t fartsgrense. Stor trafikk.	Statens vegvesen/ STFK planlegger nedsetting av fartsgrensen på strekning forbi skolen	SVV/STFK
4	Kryssingspunkt, Eidsvolls gate mot skolen	Problematisk kryssingspunkt ut fra fartsnivå og trafikkmengen i vegen.		SVV/STFK
5	Øvre allé	Stor sykkeltrafikk som oppleves som trafikkfarlig for fotgjengere.		TK
6	Kristianstensbakken	Tilvekst av vegetasjon skaper siktproblemer langs vegen. Ønske om fartsgrense 30 i hele Kristanstensbakken. Ønske om enveisregulering av trafikk på strekningen fra avkjørsel til festningen til Skansegata	Trafikkreguleringer må vurderes i forhold til reelt fartsnivå og ut fra virkninger for tilgrensende gater.	TK/private grunneiere
7	Elvepromenaden	Manglende gjerde mot Nidelva oppfattes som sikkerhetsproblem		TK
8	Rogerts gate	Ønske om utbedring av fortau på strekningen, som er viktig som skoleveg	Vurdere muligheten for tiltak. Forholdene på strekningen og ved skolens inngang utbedres på kortere sikt gjennom parkeringsregulerende tiltak	TK

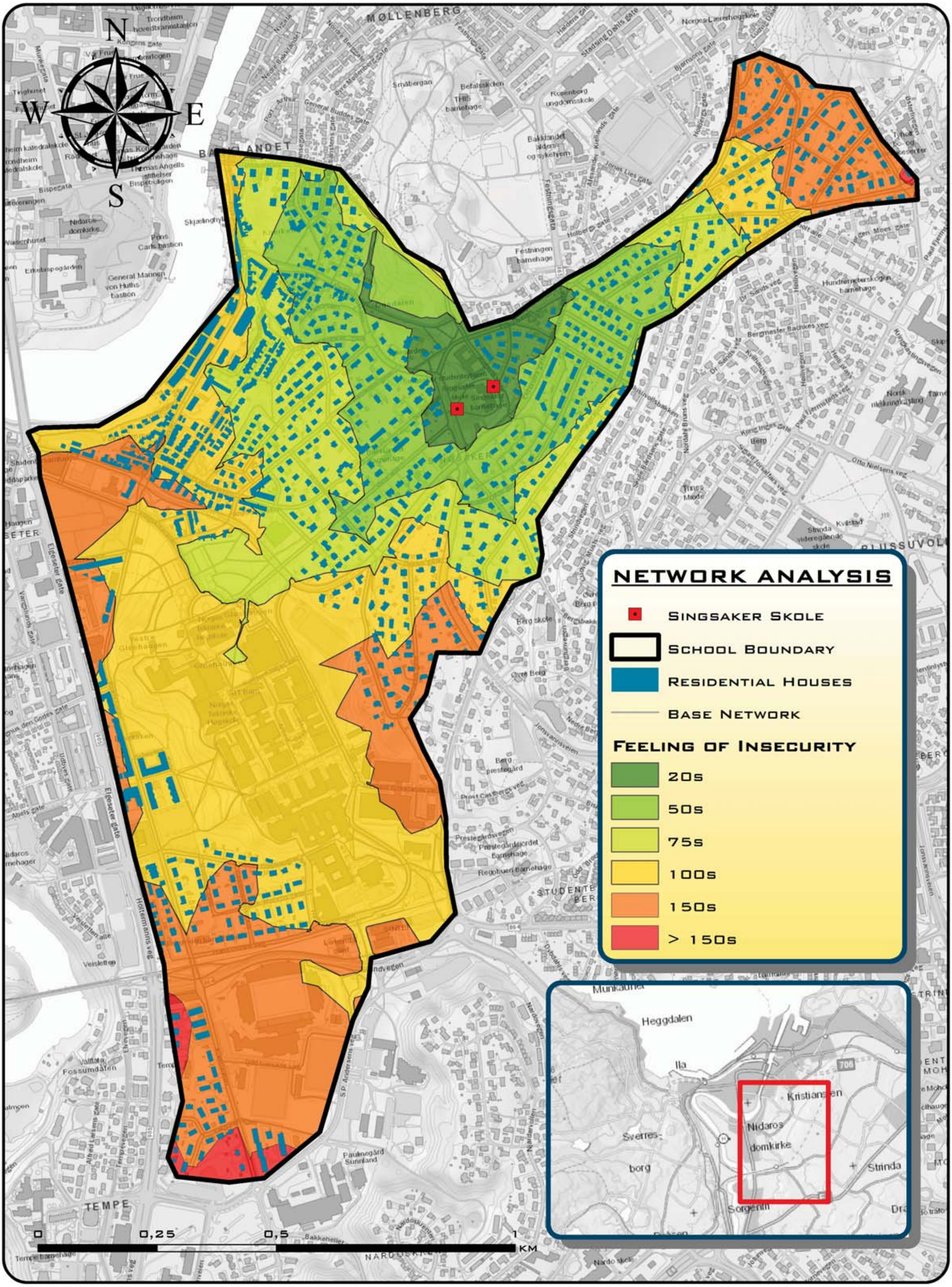
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
5 A	Alejandro Garcia-Torres F.	School Selection	Trondheim, Norway	2017



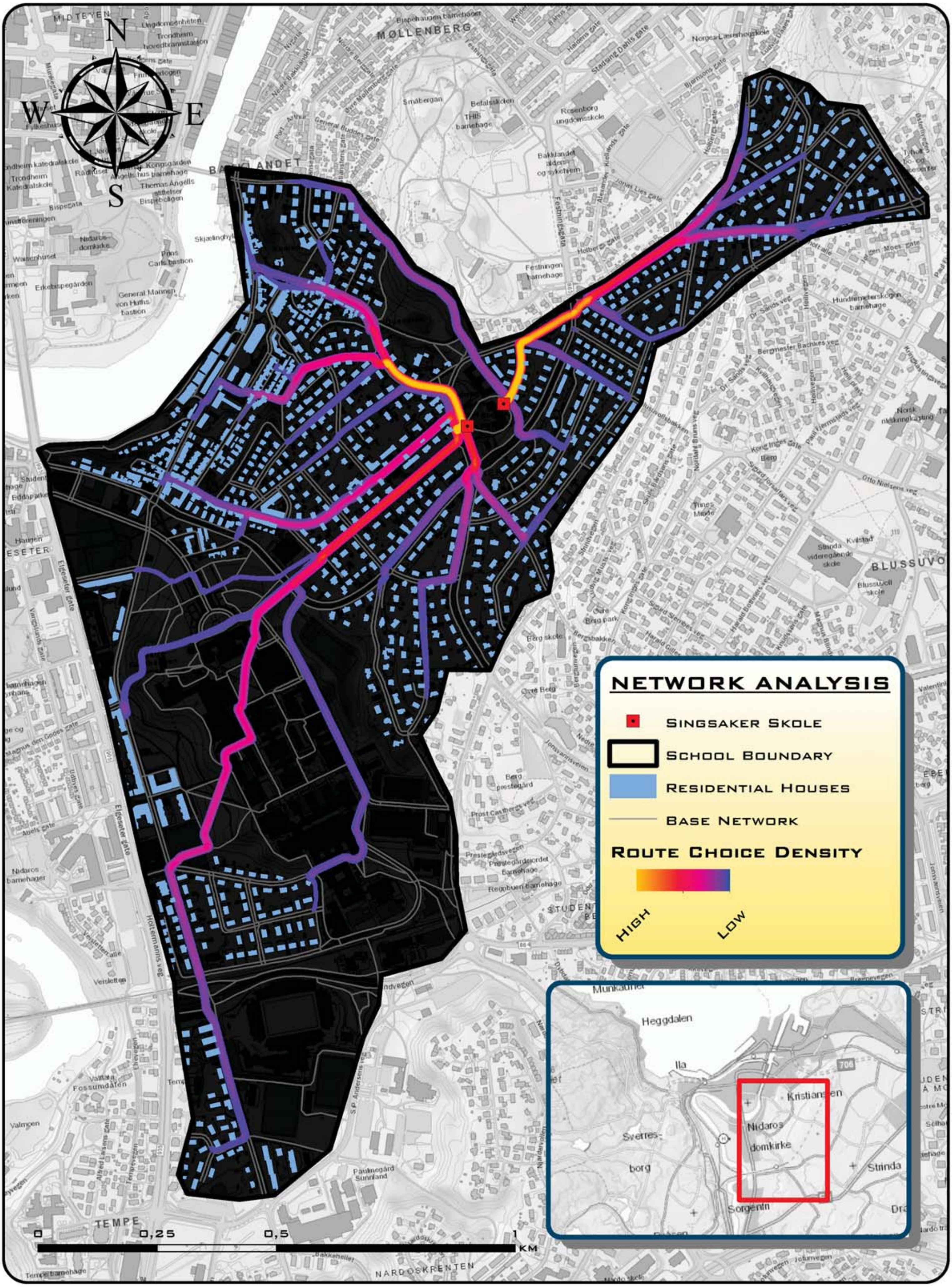
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
5 B	Alejandro Garcia-Torres F.	Accessibility (Walking Time)	Trondheim, Norway	2017



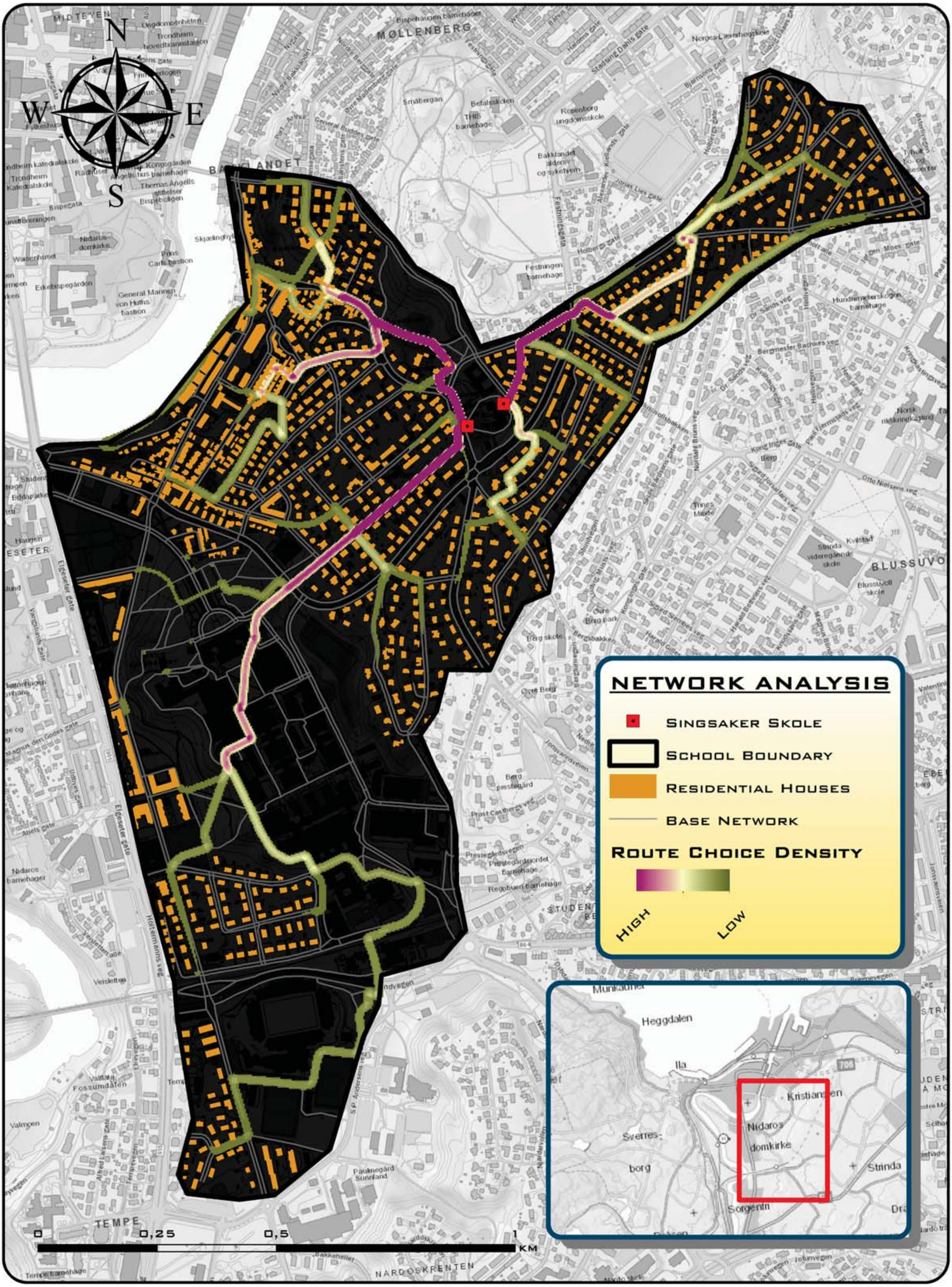
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
5 C	Alejandro Garcia-Torres F.	Accessibility (Insecurity Time)	Trondheim, Norway	2017



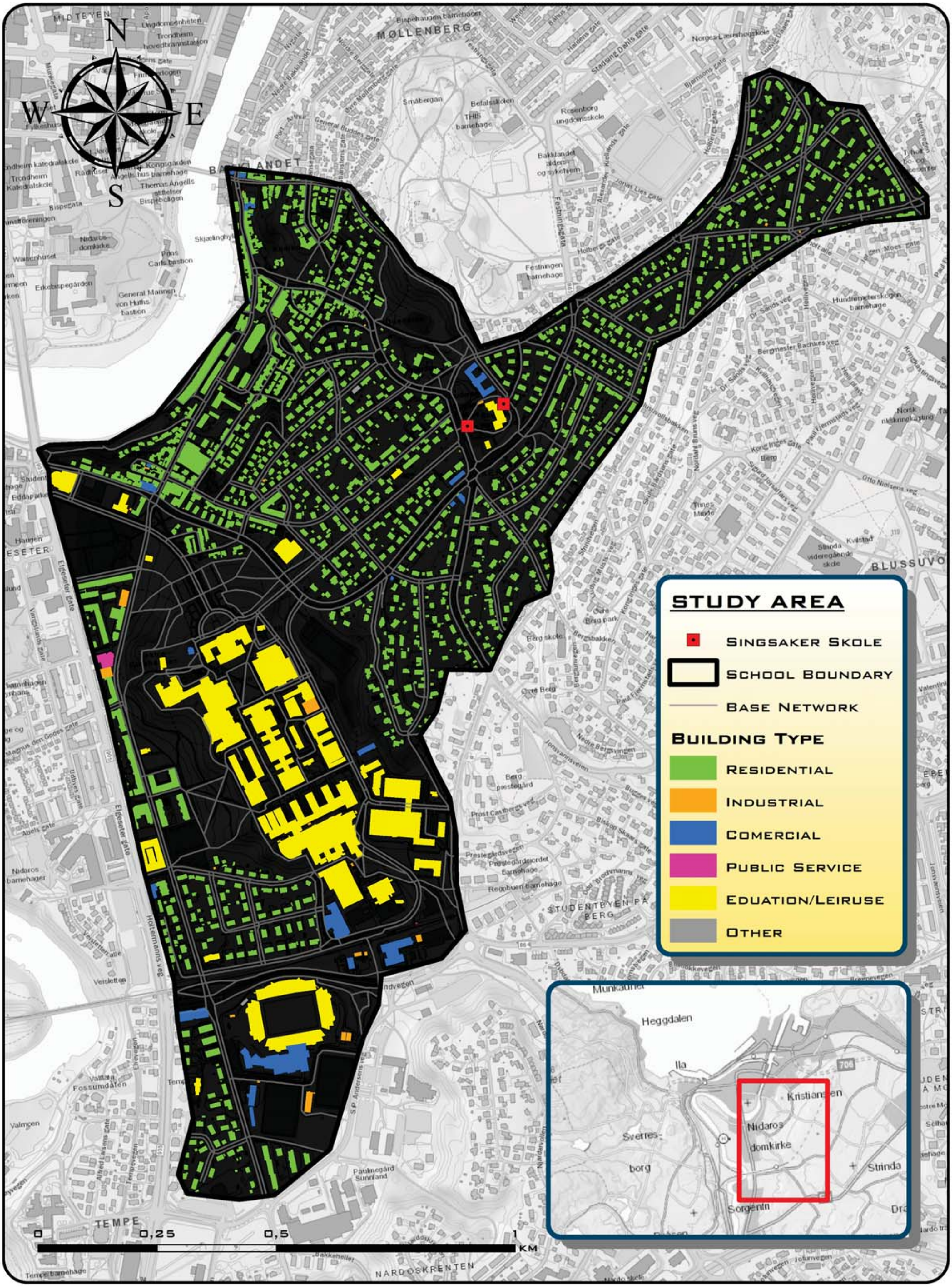
Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
5 D	Alejandro Garcia-Torres F.	Shortest Corridors	Trondheim, Norway	2017



Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
5 E	Alejandro Garcia-Torres F.	Lowest Insecurity Corridors	Trondheim, Norway	2017

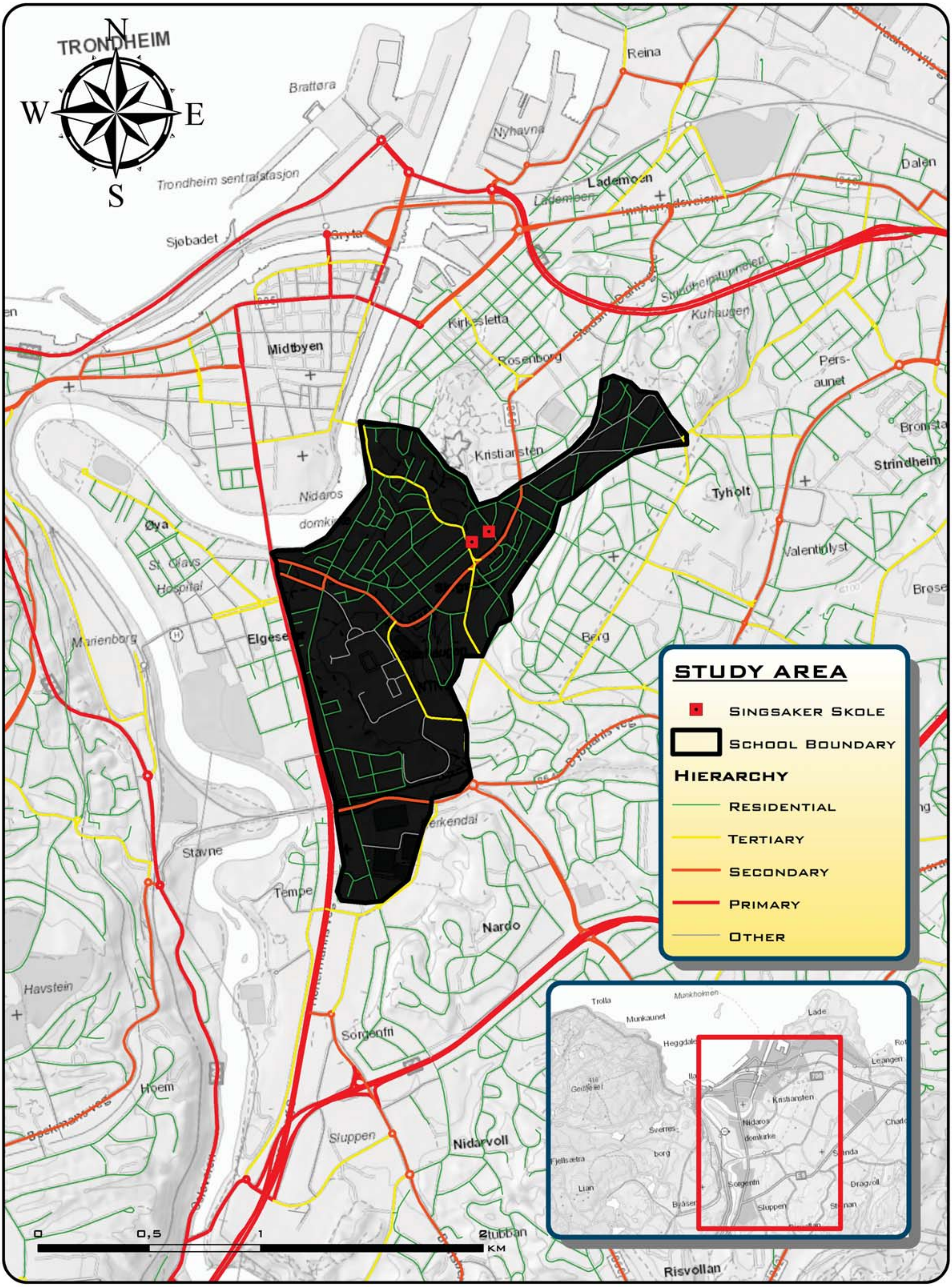


Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department				
Code	Author	Map Set Appendix	Location	Year
5 F	Alejandro Garcia-Torres F.	Building Distribution	Trondheim, Norway	2017



Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department

Code	Author	Map Set Appendix	Location	Year
5 G	Alejandro Garcia-Torres F.	Street Hierarchy	Trondheim, Norway	2017



Norwegian University of Science and Technology (NTNU) - Civil and Transport Engineering Department

Code	Author	Map Set Appendix	Location	Year
5 H	Alejandro Garcia-Torres F.	Accessibility (After Measures)	Trondheim, Norway	2017