Automatic generation of levels of detail

A study on the Swedish National Road Database

ALEXANDRA BÖRJESSON
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Abstract
When creating a map, the amount of data and which geographical information chosen to be presented are decided based on the purpose of the map. Trafikverket is responsible for the National Road Database that is a reference road network with a large amount of data connected to it. The database is built at a carriageway level where several links can be used to represent a single road. In this thesis the database has been studied as well as the possibilities to create an automatic workflow that creates a generalisation to road level. Some applications and analyses that use this database are requesting input data of a higher level of detail. It is also found important from a cartographic point of view. Possibilities to create a linear referencing for the data between the different levels was studied as well, to make the updates between the levels easier and not having the need to maintain two different databases. It would make it possible to inherit attributes and the generic features connected to the network.

The first fully automated workflow for a generalisation of an entire map was developed in the Netherlands in 2014. Several other agencies in Sweden and Norway are currently working on generalisations as well and using different approaches. Statens Vegvesen, which is the National Road Agency in Norway, has already implemented the different levels of detail in their road database. Lantmäteriet currently has a project where their goal is to create a fully automated map to easily change to a larger scale.

After studying the programs used in other generalisations and which programs Trafikverket normally use, FME and ArcGIS were chosen to be used in this thesis. A small study area was chosen, and the proper data was collected from the National Road Database. The study was conducted by a set of experiments and trying different parameter values in order to obtain a satisfactory result.

Three different areas where studied, where the goal was to find a sequence of functions that successfully generalised all the areas. The areas were parallel roads, complex intersections and roundabouts. The result consists of a suggested workflow, but alterations had to be made manually since it was not possible to find a fully automated generalisation for the area chosen. Therefore, a set of functions and tools that could be developed were collected as well in the end to make a more automated workflow possible.

The result found in this thesis show that if the cartographic generalisations are more studied and examined it should be possible to get a more automated workflow to create a generalisation between the different level of detail. However, it might be difficult to get the workflow fully automated due to the complexity of the intersections.

Keywords: Cartographic generalisation, transport network, database, levels of detail, geographic information system, GIS, FME
Sammanfattning

Svensk titel: Automatisk generering av detaljnivåer


Efter att ha studerat de olika program som vanligtvis används vid generaliseringar samt vilka program som Trafikverket använder sig av så valdes FME och ArcGIS i det här arbetet. Ett mindre studieområde valdes ut och relevant data hämtades från den Nationella Vägdatabasen. Studien bestod av olika experiment och tester av olika parametravärden för att få ett acceptabelt resultat.


Resultatet av det här arbetet visar att om kartografiska generaliseringar studeras och testas mer skulle det kunna vara möjligt att skapa ett mer automatiserat arbetssätt med syfte att möjliggöra generaliseringar mellan olika detaljnivåer. Det kan däremot vara svårt att få detta helt automatiserat på grund av de olika komplexa trafikplatserna.

Nyckelord: Kartografisk generalisering, vägnät, databas, detaljnivå, geografiska informationssystem, GIS, FME
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>EVA</td>
<td>Effekter vid väganalyser</td>
</tr>
<tr>
<td>FME</td>
<td>Feature Manipulation Engine</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
</tr>
<tr>
<td>IPA</td>
<td>Indataförsörjning för prognos- och analysverktyg</td>
</tr>
<tr>
<td>NVDB</td>
<td>National Road Database</td>
</tr>
<tr>
<td>TNE</td>
<td>Transport Network Engine</td>
</tr>
</tbody>
</table>

Dictionary

Since this thesis is conducted at a Swedish Agency, there are words that have several possible translations. Therefore, some of the most important translations used is collected in the dictionary below.

<table>
<thead>
<tr>
<th>English</th>
<th>Swedish</th>
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<tbody>
<tr>
<td>Branch</td>
<td>Gren</td>
</tr>
<tr>
<td>Carriageway level</td>
<td>Körbanenivå</td>
</tr>
<tr>
<td>Complex intersection</td>
<td>Trafikplats</td>
</tr>
<tr>
<td>Generic feature</td>
<td>Företeelser</td>
</tr>
<tr>
<td>Host road</td>
<td>Värdväg</td>
</tr>
<tr>
<td>Lane level</td>
<td>Körfältsnivå</td>
</tr>
<tr>
<td>Sibling backward</td>
<td>Syskon bak</td>
</tr>
<tr>
<td>Sibling forward</td>
<td>Syskon fram</td>
</tr>
<tr>
<td>Swedish Road Administration</td>
<td>Trafikverket</td>
</tr>
<tr>
<td>Road level</td>
<td>Vägnivå</td>
</tr>
<tr>
<td>Roundabout</td>
<td>Cirkulationsplats</td>
</tr>
<tr>
<td>Slip roads</td>
<td>Avfart- och påfartsramp</td>
</tr>
</tbody>
</table>
1. Introduction
The infrastructure is the facilities, services and organisational structures available for the residents. The infrastructure can include roads, tunnels, bridges, mass-transit systems, waterways etc. (Craven, 2019). These systems are widely used and expected to function at all time. In Sweden these are maintained with governmental founds and taxes. The infrastructure is payed for and used by everyone in Sweden, and most people are depending on a functioning transportation system.

Accurate public road and traffic data are some of the key elements of intelligent transport systems. This helps to guarantee the availability of intelligent digital maps to allow navigation, travel planning and different kinds of traffic management applications. The number of applications that rely on the availability of accurate and reliable spatial data is increasing (European Commission, 2019). Therefore, it is important to make sure that the road databases are safe and easy to access.

This thesis has been conducted at Trafikverket (the Swedish Road Administration) and a study on the Swedish National Road Database.

1.1 Background
Trafikverket, is the Swedish government agency that is responsible for the sustainable infrastructure for the road, rail, sea and air transport. They are responsible for planning, constructing, operating and maintaining all state-owned roads and railways in Sweden. In 1996 the government gave them the task to build and maintain the National Road Database, also called NVDB (Trafikverket, 2019a).

NVDB is a Swedish reference road network, with a large amount of data connected to the road network through generic features. It contains all roads in Sweden owned by either the government, a municipality or private. It is a collaboration between Trafikverket, the Swedish Transport Agency, The Swedish Association of Local Authorities and Regions, forestry and Lantmäteriet. Today it serves as an open data source that is used for both commercial and public applications within road informatics (NVDB, 2019). Many applications use this data source, and it is therefore important to maintain and keep the database easily accessible.

When mapping a transport reference network, it is a representation of the real worlds transport network, and therefore it can be represented with more or less details, depending on the purpose. It is important to always maintain an accurate representation of the reality, regardless of the amount of detail. In the reference network in NVDB, each link represents a carriageway. This results in one highway being represented with two lines and intersections can be represented with two or more links, as seen in Figure 1. Some applications demand fewer links and less detail in order to function. For these applications it would be useful to have the data on a road level, where a single link would represent several carriageways. It also beneficial from a cartographic point of view to be able to visualise the data at another level of detail.
There is already a request of a reference network on a road level for some analyses conducted at Trafikverket. When analyses today are created, a generalisation from the existing carriageway level to the road level is done by a generalisation tool they have developed themselves. This tool is however not effective enough and parts have to be manually altered. Other users that use the data stored in NVDB have also requested a road level. For example, when analysing if a wildlife fence is reducing the amount of accidents, it is not effective to study the amount of accidents for the carriageway. It is more relevant to study the amount of accidents on the given road segment before and after the wildlife fence was installed. From a cartographical point of view, it can be useful to have a higher level of detail. This can make maps at a greater scale more visible and improve the readability. A road level would also request a reduced amount of data storage.

The Information Model Transport Network that Trafikverket has implemented allows representation of the links at different levels of details, but it is currently not used in the database.

1.2 Generation of a new level of detail

When creating maps and dealing with spatial data, it is a representation of the real world and can be visualised in several different ways. The level of detail, complexity of the map and which objects to visualise depends on the purpose of the map and which information that should be presented. The visualisation of data at different levels of detail and scales might be crucial for different applications. When viewing data at a large scale, the user might be interested in more details than when the same data is viewed at a smaller scale. The use of simplifications and different level of detail is necessary in many different applications. It is favourable to make this automatically to avoid a large amount of manual work. When the new level of detail is achieved, it can easily be updated automatically if needed.

This generation to another level of detail is desirable to do by a cartographic generalisation which involves selection of features to survive and remove, and simplification of data. In order to make this generalisation between the different levels of detail automatically there is a need to distinguish the information that is important to keep between the levels and find a generalised way of making the transformation.
1.2 Objective
The objective of this thesis is to investigate the possibilities and obstacles with creating automatically generalised spatial data at other levels of detail. Previous work and similar issues will be studied, and the result will be applied to the National Road Database for Trafikverket where the road reference network consists of links representing the carriageways.

The goal is to get a better understanding of the issue and to study if it is possible to develop an automated workflow that implements operators in the right order to get the links to represent several carriageways instead. The possibility to connect the links between the different levels of detail will also be examined, in order to make it possible for the generic features to be inherited between the levels. Alternative options and suggestions will be presented.

1.3 Scope and limitation
In this thesis, only existing tools and programs will be used. These tools need to be evaluated and parameterized in order to meet the requirements. Due to the limited time, some of the data will be manually altered in order to analyse different ways of generalisation. Suggestions of how to alter the data in order to fit the requested data will be provided throughout the thesis.
2. Previous work

Generalisation is a task that have been important when creating maps, both cartographic and to ease tools used on the data. The history of the issue has been studied as well as successful examples of generalisations on data. Interviews have been held with agencies in Sweden and Norway that are studying the same issue in order to understand their possibilities and obstacles.

2.1 Cartographic generalisation

In 1967, the International Cartographic Association defined cartographic generalisation as “the selection and simplified representation of detail appropriate to the scale and/or the purpose of a map” (Stern, et al., 2014).

Map generalisation is the process of transformation between different levels of detail on a map to improve visibility and readability between graphic phenomena. The features desirable to preserve for the purpose of the map is selected in a way to make the map clear and informative. The generalisation is often made dependent to the scale, where the smaller the scale is, the greater the generalisation required. This results in a small scaled map containing the most important objects and eliminates or combines the less important objects. When making a generalisation the user needs to define the requirements, the geographical data to visualise, the readability rules and the means of the generalisation (Stern, et al., 2014).

There has been an increasing focus on the data and geographical databases and how they are stored. The idea is that the database is the first abstraction of the reality and by generalising, the features are visualised in a map (Mackaness, et al., 2007). When new models are developed the researcher is understanding more and more the importance of the underlaying data and more focus is placed on the data. There are two common types of generalisations; semantic and geometric (Abdelsalam, 2001).

Semantic generalisation

The semantic generalisation is based on the choice of relevant data to be presented and simplify the given data. Two important processes used in this type of generalisation is the combination and classification of the data. The classification is useful in order to organize objects, which helps when grouping objects and representing them with a single object (Abdelsalam, 2001). The main objective with this process is to simplify the presented data. This generalisation is often performed before the geometric generalisation (Stern, et al., 2014).

Geometric generalisation

The geometric generalisation is based on manipulation of the graphic characteristics of the features. This generalisation is based on the classification and combination of features on the map, where the goal is to preserve the important parts and simplify or eliminate the less important. There are several techniques of geometric generalisation procedures available, some are presented below in Figure 2. When choosing the techniques to use, the user needs to determine the goal of the process, for example if the goal is to reduce the amount of data or to enhance the appearance of the map.
2.2 Generalisation of digital maps

Due to the usage of different scales in maps, there has always been a demand of cartographic generalisations. With digital maps the ambition to automating the process is born and explored. Today digital maps are being more and more used and the demand for updated and accurate maps is high.

For national mapping agencies that are responsible for producing and maintaining topographic data, automatic generalisation is important in order to increase the efficiency of data at different scales and to allow customised data products (Foerster, et al., 2010). This is also important in order to reduce data production cost and also to improve the data maintenance. The objectives with the research by Foerster, Stoter and Kraak (2010) is to get an insight in the automatic generalisations that different national mapping agencies use. In the paper, the generalisations are described as mostly a subject to research and only a few have been used in practice. This is mostly due to the complexity, incompatibility of data models and lack of generic view on the requirements.

Mackaness, Ruas and Sarjakoski (2007) discuss why generalisation is so difficult to automate. Four different possible reasons are presented; the first is that the process of design is complex. Different solutions may exist, reflecting different constraints. This creates a problem to stay objective when generalising. A second reason is the change of information, when the scales are changed. Different level of detail presents different characteristics and relationships. Even
with the same database, different results are obtained. The issue here is that no one is more correct than the other, and it is therefore difficult to say which solution is better.

The third issue described is to see the generalisation as a modelling problem. The fourth and final problem described is the interaction in the map generalisation modelling process. This raises the question of what the optimal balance is between human and machine in the process.

2.2.1 The National Mapping Agency in the Netherlands
The National Land Registry and Mapping Agency in the Netherlands are responsible for the topographic mapping of the entire country. Each two years they manually update the topographic vector data and raster maps on the scales 1:10 000, 1:50 000, 1:100 000, 1:250 000 and 1:1 000 000. This process is taking a long time and is too costly to meet the required update cycle. These problems motivated a research that resulted in the first fully automated workflow, where a 1:50 000 map was generalised from a 1:10 000 map (Stoter, et al., 2014). The resulting map was good enough to replace the existing maps.

The research “Fully automated generalisation of a 1:50k map from 1:10k data” was made by Jantien Stoter, Marc Post, Vincent van Altena, Ron Nijhuis and Ben Bruns in the Netherlands. In their project they used mostly existing tools, which main problem is that it is difficult to parameterize.

The generalised map contains different types of data, covering the entire Netherlands. After the generalisation the networks, roads and rivers, are still connected. This is the first time that a fully automated workflow has been conducted without any human interaction. The workflow consisted of 200 operations using relevant algorithms and parameter values. It consisted of 36 parallel processes in Python to complete the generalisation. 100 % automation was possible because the map specifications were adjusted to meet the technological possibilities.

Their workflow was divided into four steps:

- Pre-processing.
- Model generalisation, with the aim to reduce the amount of data that has to be visualised.
- Symbolisation of the data.
- Graphic generalisation to solve the cartographic conflicts of symbolised objects.

The entire dataset of the Netherlands was completed in one run. The experiments made showed that if the input data is good and correct, the result will be better. Therefore, it is valuable to put attention to enhance the input data and correct the errors that might occur. Their conclusion from this project is that the automated map generalisation will bring a revolutionary change in the product and the workflow.

2.2.2 Generalisation on networks
When dealing with features that represent network structures such as roads, railways etc. some extra attention is required (Mackaness, et al., 2007). After the generalisation the
network needs to be maintained and there should not be any gaps between the line features, to make sure that the network still represents the real network.

Some of the researches on this area are focused on reducing the density of the network without losing the connectivity between the lines, while other focus on simplifying the roads themselves. In this thesis, both the density needs to be reduced as well as the lines simplified. At smaller scales it might not be possible to show all the links and junctions; in that case they need to be simplified. When these operations are performed, it is important to maintain both the connectivity as well as the characteristic form.

2.3 Generalisation at different agencies
During this thesis, two different agencies have been contacted and interviewed in order to understand how this issue is handled at different agencies. The existing generalisation that is used in some parts of Trafikverket will be analysed as well.

2.3.1 Lantmäteriet
Lantmäteriet is the agency in Sweden that is responsible for mapping entire Sweden, as well as registering the ownership and the boundaries of the properties. They are also involved in the maintaining of NVDB. The maps, data and images produced are publicly available. Today, the focus has shifted from the printed maps to dynamic digital maps. With digital maps it has become more important to have the data up to date and as accurate as possible.

Recently, Lantmäteriet has started to build an automatic generalisation to go from the map at scale 1:10 000 to 1:50 000 and in the future to even smaller scales. The estimated project time is 2015-2022. This project is made at all the data including polygons, points, lines and networks. The purpose for this is to increase the effectiveness for the databases and the map products. They also want to create a more cohesive and flexible production and being able to make the updates faster at several scales. An example of the generalisation made by Lantmäteriet is shown in Figure 3.

Lantmäteriet is mostly using ArcGIS and the Model Builder to make this generalisation, but FME is also used for some parts. The functions used are mostly the built in but in some cases, own functions and tools has been developed. The parameter values were determined empirically. For example, the roundabouts less than 30 meters in diameter will be replaced by a simple intersection, and all other roundabout will be visualised as 50 meters after the generalisation. Important roads have been manually marked with “Very important objects” to

Figure 3: The input data on the left, the automatically generalised 1:50 000 data on the right (Lantmäteriet, 2018).
make sure they will not be removed during the generalisation. In the same way, unimportant objects that should be removed were also identified and manually marked. So far, they have not been able to create a fully automated workflow for the generalisation. The data is split into cartographic partitions to reduce the input data and therefore making the process faster. The partitions are buffered and after the operations have been run, the partition is matched with the surrounding partitions to make sure that the network still is complete, and all road links can be used.

One conclusion made so far is the importance in having high quality of the input data and removing all errors before starting the generalisation instead of creating error correction in the process (Lantmäteriet, 2019).

2.3.2 Statens Vegvesen
Statens Vegvesen is the Norwegian Public Roads Administration. They are the equivalent to Trafikverket and are responsible for the planning, construction and operation of the national and county road networks (Statens Vegvesen, 2019a). Their information about the road network and the information connected to it is saved in the Næsional Vegdatabank (NVDB). It is stored using the Transport Network Engine (TNE), similar to how the Swedish National Road Database is stored.

The Norwegian NVDB uses three different levels of details; roads, carriageways and lanes. The road level is the one with the least amount of details. It only describes where the roads are located, where the roads cross each other, where there are roundabouts and where slip roads are located. The level with carriageways is the complete level, where all the links in NVDB are registered. In a variety of places, the roads and the carriageways are identical, and that data is saved at the carriageway’s level of detail. The level with the lanes is the most detailed level. It does not cover the entire country, just the parts where it is needed, for example where there are specific fields for turning. A visualisation of the three different levels is shown in Figure 4 below.

![Figure 4: An intersection with the road level at the top, carriageways in the middle and the lanes at the bottom (Statens Vegvesen, 2018).](image)

The links in the different levels of detail are connected to the others and know which links it corresponds to on another level. Both the road level and the lane level are connected to the carriageway level, due to this level being the only level with complete coverage. The different levels can partly, or completely be the same as another level.

To the link network, different generic features are connected. These features are connected using linear referencing and the feature know to which link in the network it belong to.
In Figure 5, all of the three different levels that are used to represent the road network is shown in an intersection. In this figure it can be seen that the road level is the one with least details, while the lane level contains the most details, and also the largest amount of data.

Statens Vegvesen have specified five demands for a road network with different levels of detail that are connected to each other, as described below:

- There is a need for several levels of detail for parts of the network: there is usually no need or data enough to have the entire road network in all of the different levels.
- The elements in the network needs to be connected at the same level: the network should be regarded with the similar perspective as the physical road network.
- The network should correspond to each other at the different levels: the link at one level should know which it corresponds to at the other levels.
- Transitions between levels of details: since it is not possible to use all different levels at once, it should be possible to switch to the other levels from the base network.
- Generic features should be able to connect to the network: it should be possible to add a geographical location to the features.

When their NVDB was created, they started to save the information at the three different levels of detail from the beginning. Therefore, the databases are built for this type of information. There are some issues with the way data is stored, for example in tunnels, where the different carriageways still need to be separated even at road level which create issues with statistics. Another issue is that it has not been consistently stored since the beginning (StatensVegvesen, 2019b).

Some of the advantages they see with having the data on road level is having the same visualisation for both a highway and a large regular road. It is also easier to use statistics, since right now a highway is represented with more than double the amount of lines than the length of the highways. The inheritance mechanism of the generic features between the different level of detail is also an advantage. For example, the speed limit is usually the same for both of the carriageways, so giving just one feature on the road level this attribute and having the
carriageways inherit the attribute is useful. It creates less data storage when representing a highway with a single link.

2.3.3 IPA (Indataförsörjning för prognos- och analysverktyg)
Trafikverket is already in need of having their data at a road level. For this, a generalisation tool has been developed, called IPA (Indataförsörjning för prognos- och analysverktyg). This is used by a few users working at Trafikverket who need this type of network for analyses and estimation programs they use. Two of the systems that need to have the input data at a road level are Sampers and EVA (Bornström, 2019).

Sampers is a national modelling system for intermodal analyses of passenger transport. It is used to estimate future traffic flows, impact assessments and investment calculations along with other different types on analyses of the traffic (Trafikverket, 2018). EVA (Effekter vid väganalys) is a tool used for calculating and estimating effects and to calculate if single objects within the road transport system is benefiting. It can, for example, calculate effects on travel time, traffic safety, emissions, operation and maintenance. Both these tools are owned and managed by Trafikverket (Trafikverket, 2019b).

The network is generalised by first removing certain classes of roads, and afterwards a series of tools are used. The work is made mostly in ArcGIS using some existing tools, but also tools that have been developed by Trafikverket. It is updated once every four years or more rarely, since it is quite time consuming due to the amount of work being made manually. The input data contain some missing attributes or general errors, which result in a need of manual alterations. If a project requires a generalisation, the area needed can be located and generalised more frequently. In this generalisation every junction is visualised with only one single node, as seen in Figure 6.
There are also some errors that can occur in the network during the generation of another level of detail. For example, at some locations the network might not be connected, which can occur when the generalisation is made since they remove certain types of classes of roads. An example of an error that has occurred while generalising can be seen in Figure 7. They have developed tools to fix different types of problems such as a polygon that locates gaps in the network, so these can be solved.

There is no connection between the different levels of detail in the IPA network, and the attributes can therefore not be inherited.
3. Methodology

Possible ways of generalising and the available operations are evaluated with the goal of finding a possible way to generalise a link network. Available programs and tools were studied. After the generalisation is built, the data need to be linearly referenced between the different levels of detail. If this is successful, the generic features can be inherited, and connected between the levels.

3.1 Available programs

GIS technology has created a shift in how geographical information is managed and interacted and there are several programs and tools available. As previously stated, this thesis is only investigating already available tools. Based on the interviews, literature studies and previous experience, two programs were chosen and used throughout this thesis. These programs were FME, which is developed by Safe Software and ArcGIS, which is developed by Esri.

3.1.1 FME

FME (the Feature Manipulation Engine) was developed by Safe Software in 1993. It is a data integration tool, used for transforming data. By using transforming tools, FME reads data from multiple sources and change or restricts the data in order to fit the users’ needs. FME supports many different data types, databases and various mapping formats, for example Excel, CSV, GIS, CAD and BIM (Safe, 2019a).

The customers are located worldwide, and are from different industries such as architects, engineers, governments, telecommunications etc. The tools are described online in their FME Transformer Gallery (Safe, 2019b) and a few of the tools used are briefly described below.

**FeatureMerger**

The FeatureMerger is used to merge attributes and/or geometry of a set of features to another set of features based on a matching key. The tool uses two input streams of features, the requestor and the supplier. The requestor consists of the features that will receive new attributes while the supplier is the provider of the attributes to be merged to the requestor.

The features matched, based on the key, will be identified and the attributes merged onto the requestor.

**NeighborFinder**

The NeighborFinder is identifying the nearest feature from the candidate to each base feature and merges their attribute to the base. The attributes that are calculated is distance, angle and the coordinates of the matches. The candidate is merged on to the base based on proximity and parameter selections.

3.1.2 ArcGIS

In 1969, Esri (Environmental Systems Research Institute, Inc.) was founded. They developed applied computer mapping and spatial analysis to help land use planners and resource managers to make educated decisions. Esri has continued developing both mapping and spatial analysis methods that are still in use (Esri, 2019).
ArcGIS Desktop consists of several applications such as ArcMap and ArcCatalog that are used in order to create maps, perform analysis and manage geographic data. ArcGIS also has functions and models to use in order to automate workflow.

One toolset available is the Generalisation toolset, which contains tools that simplify or refine features for display at smaller scales (Esri, 2016). Since this thesis only focuses on networks and lines, not all of the tools in the toolset are used. The tools used are briefly described below.

**Merge Divided Roads**
The tool Merge Divided Roads locates line features and combines them into one single centre line. The input for this tool is the linear road features that the user wants merged along with a merge field that contain classification and the merge distance. The merge field consists of road classification information, where a value of zero will be locked and not part of the merge. The value in the merge distance is the maximum distance between the road features, in order for the features to be merged into a single line.

![Figure 8: A result after the tool Merge Divided Roads is used.]

The road features need to be in the same road class and relatively parallel in order to be merged. The output file contains the merged features that fulfilled the requirements, along with the unmerged features. Figure 8 shows an example of how two parallel roads in the road network were merged into a single road feature.

**Thin Road Network**
This tool simplifies road network but retains connectivity and the general character of the network. The input for this tool is a linear road network that should be thinned. The minimum length should define the shortest road segment that should be displayed in the output. The invisibility field is the field that stores the result, since this tool do not remove any features. The features that should participate after the simplifications will have a value of zero, while the others will be given the value one. The hierarchy field contain the importance of the feature. The features given the value one are considered very important, and zero are the features that should remain visible after the operation.
After the tool is used, the invisibility field can be evaluated, and the features given the value 1 can be considered as the unnecessary features and removed before continuing the generalisation. As seen in Figure 9, the tool has identified two features that are not needed in the simplified network and these values has received a value of 1.

**Collapse Road Detail**

This tool identifies small open structures that interrupt the general trend of the road network and replaces them with a simplified segment. These features could, for example, be roundabouts and junctions.

The input in this tool is the road network that contain the road details that the user wants to be collapsed. There should also be a collapse distance, which can be considered as the maximum diameter or the distance across the road detail in order for the feature to be collapsed.

The output consists of the features that were collapsed during the run, and also the unaffected features. In Figure 10, it is possible to see how a roundabout is collapsed to a single road feature and connecting the two road features leading up to the roundabout.
3.2 Research strategy

In 2012, Trafikverket had a project called Project New Information Models that created a report called Information Model Transport Network – Road and Railway. This is an information model that is created primarily to manage the internal needs within Trafikverket. This document is describing the transport network and the purpose, architecture and usage of the network.

![Diagram](image)

**Figure 11: Relations between the network, operating data and geography (Project New Information Models, 2012).**

The relations between the different parts can be seen in Figure 11. The reference network describes the main properties of the actual network and how the elements in the network are connected. This network has the geometry along with descriptions of the location relative to the Earth. The reference network will be used as a reference system where other features can be connected. The requirement is that the elements of the network have stable identities and are reliable over time.

The generic features can include anything that have a logical or physical connection to the network. The features can for example be equipment associated to the road, such as signals or signs, events such as accidents, administrative portions such as road number or regulations such as speed limits.

The generic features are connected using coherent mechanisms to make sure the features can be found in a uniform manner regardless of the type so the different features can be regarded and compared to each other in relation to the road network. Through this, the features also get a connection to the geography. This is described as the Network connection, which can be seen in Figure 11.
As seen in Figure 12, The Information Model Transport Network that Trafikverket have implemented allows representation of the links at different levels of details. It has recently been implemented but is still optional and not used today.

In this thesis, the goal is to analyse the possibilities and obstacles with creating the automatically generalised reference network. Therefore, different approaches and methods were performed and analysed. Some parts might be manually altered with the goal to find out which alterations that should be made in order to make the generalisation possible. The attributes and the alterations made in this thesis are following the regulations stated in the Information Model Transport Network – Road and Railway to make sure Trafikverket will be able to implement it.

3.3 Identification of the influential factors and the need of data collection
It is important to keep a cartographic generalisation as objective as possible, making sure that the user performing the generalisations will not affect the result. This is usually a difficult task when it comes to cartographic issues. Therefore, it is important to identify the demands on the finished products, and what the road level will be used for. It is crucial to identify which parts that are important to preserve and which parts that can be altered and simplified.

The National Road Database contains different generic features, connected to the link-node network. It contains all links created since the beginning and which time periods the link was valid. By analysing the data available in the database, the important network links, generic features and attributes needs to be identified and collected.

3.4 Choice of methods for data collection, data processing and analysis
Since the generalisation of one element will affect the generalisation of others it is important to find a procedure that follows a specific automated sequence. This thesis is built on experiments to find an appropriate workflow, along with studies on similar work to get an insight in their work.
The two programs used were FME and ArcGIS, which are widely used and available at Trafikverket. Statens Vegvesen used QGIS for parts of their generalisation (StatensVegvesen, 2019b) as well but it was excluded in this thesis due to time restriction.

While managing the data, three different areas were chosen to focus on since all these are crucial for the reference network and important for creating an acceptable map generalisation. The first area are parallel roads since those are a large part of the network, and all highways are represented with several links. The more complex intersections are a more difficult issue, and therefore special focus was put into their generalisation. They can consist of different amount of links and can be of different complexity. The last area is the roundabouts, since it is important to keep them circular and maintain the shape even after the generalisation to represent the reality as accurate as possible.
4. Data collection

TNE (Transport Network Engine) is a platform that Trafikverket uses for NVDB. The transport network is built as a reference system to where features such as equipment, construction properties and states can be connected to provide location, shape and relationships. The features are connected to the reference system by relations with elements in the network. Therefore, the features do not need to have any position or shape data since these are obtained from the reference system via the relations. One advantage by having it as a reference system is that it makes it easy to find all features connected to a certain part of the network and easily compare them to each other.

The road network in NVDB is describing the network as a set of interconnected linear links interconnected via nodes. The nodes are located either at the end of a link, or as a connection between two or more links. The class LinkSequence describes a sequence of transport links for the reference transport network. Each of the element in the reference network has a unique object identification number that the other classes are referenced to.

As previously stated, there is a big importance in the processing of the data before the generalisation. If the input data is correct, the tools and operations will be easier to apply and provide a better result. Therefore, this part is crucial for the thesis.

4.1 Selection of sites

The National Road Database consists of a large amount of data, since it covers all the roads in Sweden. The data also contain road features that are no longer valid. To minimise the data processing, only the features valid today was chosen to be included. A limited area was chosen for testing the operations and workflow.
The chosen study area is shown in Figure 13. The area is located north of Stockholm, in the municipality of Sigtuna and located close to the airport Arlanda. This area is chosen since it has two more complicated junctions, a few simpler junctions, several roundabouts and parallel road features that need to be merged.

As seen in Figure 13, there are roads that need to be generalised, along with roads that will remain the same throughout the generalisation. This is since these roads are already visualised as a single feature where it represents the road level.

4.2 Data collection
The data is saved as different classes in the database with different attributes connected to them. The files were evaluated, and the attributes needed are described in Table 1 below.
Table 1: Description of the data collected from the database.

<table>
<thead>
<tr>
<th>Attributes requested</th>
<th>Description of data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TNE_LINK</strong></td>
<td><strong>VALID_TO</strong> – selecting all valid links. <strong>TOPOLOGY_LEVEL</strong> – The topological detail level for each Link. All the database links. All the links are connected to a LinkSequence through a unique identification.</td>
</tr>
<tr>
<td><strong>TNE_FT_Vagnummer</strong></td>
<td><strong>VALID_TO</strong> – selecting all valid links. <strong>ROLE</strong> – 1, 2, 3 or 4. <strong>Huvud_13</strong> – The route number. <strong>ISHOST</strong> – True if the road is host. Generic feature connected to LinkSequence. Contain all state-owned roads and the route number of the link.</td>
</tr>
<tr>
<td><strong>TNE_FT_FunktionellVK</strong></td>
<td><strong>VALID_TO</strong> – selecting all valid links. <strong>Klass_181</strong> – 0-9 indicating the importance of the link. Generic feature connected to LinkSequence.</td>
</tr>
<tr>
<td><strong>TNE_FT_Cirkulationsplats</strong></td>
<td><strong>VALID_TO</strong> – selecting all valid links. Generic feature connected to LinkSequence. Contain all intersections that has a roundabout.</td>
</tr>
</tbody>
</table>

The attribute **VALID_TO** defines the end of the period where the link is valid. All the chosen links are valid to 99991231, which mean that there is no end date for the link. In FME, the four files were added to the reader and by using the FME tool FeatureMerger, the data is created. The outputs from FME are Esri shapefiles, in order to be able to apply the operations in ArcGIS.
Figure 14: The workflow in FME where the data is collected from the database.
The workflow in FME is described briefly in Figure 14 above. The TNE_Link is combined with the class TNE_FT_Vagnnummer to get the attribute Role. This attribute contains four different values; where Role one means that the link is a two-way street, called normal. Role two and three are used for the roads divided into the two carriage ways, where they represent two directions of the road and usually referred to as sibling backward and sibling forward. The fourth Role is used to represent branches in the road. The four Roles are visualised in Figure 15.

![Figure 15: The four roles used in the transport network (Triona, 2018)](image)

There are some errors in the input data, where the classification of Roles is not consistent in all the areas. To solve this, every single feature of role four were examined where the connecting features were studied, and the feature should not have a lower Role than the connecting features. That results in the features with role four, that is a connection between two other features, receiving the same classification as the features it is connecting. This is to avoid the transport network not being connected. An example of the different Roles used in the transport network can be seen in Figure 16.
Figure 16: Visualisation of the four different Roles represented in the TNE_LINK network.

When the files are combined using FeatureMerger, the output features all have the attribute Ishost as True. That imply that the feature with this valid is a host road. That implies that where there are several road features with different route numbers, one is the host road and considered the most important. By using this filter, no feature should share geographical location.

The FeatureMerger is used to collect the attribute Klass_181 as well. This column describes a classification on each of the road segments with a number from zero to nine where the lower the number, the more important this segment has been ranked for the road network. This hierarchy can be used in the functions to make sure that the most important roads will remain, and also making sure that the generalisation will be kept objective from the creator of the generalisation. One issue with this data is that the classification is not the same in entire Sweden, which results in the same class not being equally important throughout the data.

The attribute Huvud_13 is also collected from the FeatureMerger. This attribute is indicating which route number each link has. The attribute is collected to be used when creating the inheritance mechanism between the different levels of detail.

All the intersections that are equipped with a roundabout are collected from the database as well and the valid links are chosen. Using ArcGIS, the diameter of each of the roundabouts are calculated. In the TNE_LINK file two attributes are added, the first is a column indicating all features that are part of a traffic circle. The other column describes the diameter of the roundabout in meter. This was processed to an Esri shapefile, in order to use it in ArcGIS.
5. Data processing
Throughout this thesis, several attempts were made using different techniques and parameter values in order to analyse and obtain the best results. The process, the possibilities and the obstacles for the different methods are described in the following chapter.

5.1 Generalisation
The generalisations are mostly generated in Esri ArcMap. There are three parts of the transport network that there is extra focus on during the generalisation; the parallel roads, the complex intersections and the roundabouts. The goal is to find a sequence of operations that creates a generalisation that works for all of these areas.

Classifications of the roads were made where the roads with the Role 1 was set as zero, since no changes should be made to these roads. For the rest of the roads, different classifications were tried, for example all other roads classified the same way or using the hierarchy Klass_181 for all roads in NVDB.

5.1.1 Parallel roads
The parallel roads are a large part of the road network since all highways and larger roads are often visualised with two road features. The goal with these roads was to merge them into a single centreline. The ArcMap tool Merge Divided Roads was used for these types of issues. This tool needs a merge distance to be specified. The distances decide the minimum distance between two parallel roads to be merged. There is benefits in having the value relatively large to include all parallel roads, but a too large distance might cause issues with other road features. Therefore, different values were tried and compared before deciding on a specific distance that satisfy both these criteria.

5.1.2 Intersections
The intersections were a more difficult task, since they can be of different complexity with several roads connecting. It is also important to keep the generalisation as objective as possible to make sure that the person generalising it will not influence the result. One of the usages of the generalised network is the analyses made at Trafikverket that require the IPA network. That requires the data in intersections to be represented with a single node, resulting in the entire intersection being generalised. Other usage, such as the cartographic aspect only require some parts of the intersection being generalised.
As previously described, the used tools will affect all parts of the network. Therefore, the workflow needs to be automated to make sure that the tools will not damage any of the other features.

Figure 17 shows how the intersection is visualised after an attempt where the ArcMap tools Thin Road Network and Merge Divided Roads were used. It can be seen that the tools damages parts of the intersection and the roads are crossing each other afterwards, making it difficult to use. To solve this issue, the most important road features of the intersection need to be identified. The attribute Klass_181 could be used for this, but as previously described the hierarchy is not consistently determined in entire Sweden. This results in the intersection in Figure 17 having only two types of classifications and it is still difficult to distinguish the most important links.

Another possible solution is to study the attribute Role, which is the same approach that was used when creating the IPA network. The Roles have been analysed and the values altered to match the criteria that all links that have been classified as branches are not needed to make the network connected. Therefore is it possible to generalise the network by removing these features without altering the connectivity. After this is done, there are less links in the network and the tools can be used with less disturbance. This is the same approach as the successful workflow created by the National Map Agency in the Netherlands.

5.1.3 Roundabout
The roundabouts were located and added as an attribute in the file TNE_LINK. This was made to locate the important areas that might need different processing. The diameter was calculated as well, using the circumference of the roundabout. The collapsed road detail was used for these areas since it locates interruptions in the transport network, such as roundabouts. In this tool, the diameter can be altered for the collapsed segments and therefore only generalising the smallest roundabouts.
In this thesis, the same approach was used as the one Lantmäteriet is doing, where all roundabouts that has a diameter less than 30 m are collapsed and considered not important. After this the larger roundabouts will be classified with the value zero, meaning that the other tools will not affect those features. This is done to make sure that the roundabout will keep its shape.

One issue that occur close to the roundabout is shown in Figure 18. Due to that the links located in roundabout are given the value zero, the links connected to it is not merged in the same way as the rest of the roads. A possible solution is to develop a tool that identifies the two parallel roads that is connected to a roundabout and merge them separately into a single feature. This was not possible to manage during this thesis due to time limitations, instead these areas were manually altered.

5.2 Inheritance mechanisms and connection between different levels of detail
In order to make the inheritance mechanism possible, a connection needed to be created between the carriageway level and the road level. With this connection, a link on the lower level of detail will know which link on the higher level it corresponds to.

In TNE it is possible to store representations on different levels of detail and it will store information about which links it corresponds to. It is a link describing parts of the network and holds information (Triona, 2018). This information is stored in TNE_LINK in the columns described below. The columns were added to the data except for TOPOLOGY_LEVEL which is already included in the database. The columns are described in Table 2 below.
Table 2: Description of the added columns.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Data type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPOLOGY_LEVEL</td>
<td>Int</td>
<td>The topological detail level for each Link. Cannot be Null.</td>
</tr>
<tr>
<td>SUPER_OID</td>
<td>nvarchar(38)</td>
<td>Object ID corresponding to the referenced LinkSequence on a higher level of detail. Cannot be Null</td>
</tr>
<tr>
<td>SUPER_START_MEASURE</td>
<td>numeric(38, 15)</td>
<td>Marks the start position on the references super LinkSequence. Cannot be Null.</td>
</tr>
<tr>
<td>SUPER_END_MEASURE</td>
<td>numeric(38, 15)</td>
<td>Marks the stop position on the references super LinkSequence. Cannot be Null.</td>
</tr>
<tr>
<td>DIRECTION</td>
<td>smallint</td>
<td>Shows what direction of the references LinkSequence this link describes. Cannot be Null.</td>
</tr>
</tbody>
</table>

The values SUPER_START_MEASURE and SUPER_END_MEASURE are using a measure value which is the distance relative to the start and end for the linear element (Project New Information Models, 2012). The measure value should be a value between 0 and 1 and referenced to where on the SUPER_OID it starts and ends.

To make the inheritance mechanism possible a linear referencing between the levels need to be created. FME is used to create the linear referencing where the input values are two different levels of detail, in this case the road and the carriageway level. The road level is the level created by generalisation and is therefore given a unique identification in FME and combined into longer features. The coordinates that creates the line are given in three dimensions, but if one is missing a z-value it is given the value -9999. This could disturb some of the functions used in FME and therefore the road level is transformed to two dimensions using the tool 2DForcer. There are other algorithms that is commonly used in NVDB when dealing with the 3D issue, and these algorithms can be used in the future. The measure value for the road level was also extracted, using the MeasureGenerator.

For the carriageway level the start and end point for the unmerged roads was extracted using the function CoordinateExtractor. For both the start and the end point the NeighborFinder was used to find the closest point on the road level, as seen in Figure 16. From this the measure values were extracted. The FeatureMerger was used to get the attributes of the start and end point to the original carriageway level, and the values for the SUPER_START_MEASURE, SUPER_END_MEASURE and the SUPER_OID was collected.
Figure 19: An illustration of the linear referencing at a simple area.

TOPOLOGY_LEVEL is describing the topological level for all links on one level, so the links on carriageway level should all have the same value, similar to the links on road level should have the same value. Some links are valid on both levels of detail and should therefore have both values.

The attribute DIRECTION marks if the link is going with or against the direction of the corresponding link on a higher level of detail. This is used to separate the two lines from each other and easier distinguish the attributes that is connected to one of them. For example, if there are street lights on one side of the road, it is important to know which side of the road it is located for maintenance.

The connection between the two levels of detail were tried out on a simple area shown in Figure 19, where two parallel links were merged into a single link. The idea would be the same for more complex link generalisations as well.
6. Results
As described in the previous chapter, different parameter values and approaches were tested throughout this thesis to identify the issues and possibilities. This chapter will present the best way to solve the issue with the given data.

6.1 Generalisations

The generalisation workflow used is visualised in Figure 20 above. The values used for the different ArcMap functions are shown in the squares on the right of the workflow. The order of the functions is important as well. All features classified as branches are removed and after that the tool Thin Road Network is used. This is done in the beginning to remove the unnecessary feature before the other tools and to reduce the amount of data before the other functions were run.

Figure 20: Workflow of the generalisation.
The function Merge Divided Road and Collapse Road Detail are only performed once for the study area, but in larger areas there might need to be performed several times with different input values in order to generalise all different parts of the reference network.

![Image: The generalisation of the study area.](image)

**Figure 21: The generalisation of the study area.**

The generalisation of the area from Figure 13 is shown in Figure 21. As previously described, three areas were focused on and evaluated separately, since they are considered important for the generalisation. These areas are described below.

### 6.1.1 Parallel roads
The first part of generalisation was the parallel roads, which is a large part of the network. The roads were easily merged using the Merge Divided Roads tool in ArcGIS and the resulting network can be seen in Figure 22 below.
The area shows an intersection with two parallel links going through it. These have been merged to a single link with the connecting links still attached, making the reference network remain connected. The connecting features have been considered important and kept in the network but could be considered irrelevant and could be generalised as well, depending on the purpose of the generalisation.

6.1.2 Intersections

The complex intersections are a challenging issue, since it can have many different shapes, forms and number of connecting links. The intersection studied was difficult to solve using the existing tools and different classifications needed to be explored in order to minimize the number of links.

In the generalisation created in Figure 23, the branches have been excluded and links simplified. It does not match the generalisation produced by the IPA-tool, as seen in Figure 6,
but can be considered simplified enough depending on the purposes. Alternative operations could be developed.

6.1.3 Roundabout
The diameters of the roundabouts are calculated, as previously described. The roundabouts with a diameter smaller than 30 m are collapsed but the greater ones are generalised, as seen in Figure 24 below.

![Figure 24: A generalisation of a roundabout. On the left is the reference network before and to the right is the reference network after the generalisation.](image)

The neighbouring roads are merged into a single central link, and the links that attaches to the roundabout is merges as well. A smaller roundabout would be represented with a single node.

6.2 Linear referencing between levels
The connection between the simple test area with two links in the carriageway level, and one single link in the road level was performed according to the workflow described in section 5.2. The links on carriageway level are connected to the higher level of detail; the road level. This results in the links knowing which link on the road level it corresponds to, the start and end measure of it and on which side it is located. By using this connection, it is enough to give an attribute to the links on the road level and it can be inherited to the links on carriageway level.

The workflow of the operations used in order to obtain the referencing is created in FME and shown in Appendix 1.
7. Discussion of the results, conclusions and recommendations

During the thesis project work it was clear that generalisation of spatial data is a difficult issue and having a fully automated map is still a challenging task. Even though the chosen area was small, it was not possible to perform a generalisation fully automatically. A lot has happened in this area in the past decade, and the fact that a fully automated generalisation of a map was created in the Netherlands in 2014 shows that this area is under development. Lantmäteriet started their generalisation project in 2015, with the goal of having an automated map by 2022. Both these projects show that creating an automated workflow for generating different levels of detail is important and with more examining of the area, might be achievable in the near future. It might be difficult to achieve a fully automated workflow and small manual alterations might be necessary.

One of the most important parts when generating another level of detail is the quality of the input data and therefore it is crucial to confirm the quality before starting the generalisation. In the previous work, it was stated that it is beneficial to limit the number of links used and exclude unnecessary features. This was clear when trying to generalise the complex intersection in Figure 17, where the roads started to cross each other and became even more complex. A possible solution for this is to reduce the number of links before the tools are used. In this thesis, one approach was to use the hierarchy Klass_181 that classifies the links in the network, but it was an issue to do so since many links in the same intersection are classified in the same way. Another issue was that it is not classified in the same way in entire Sweden, so even if the study area would be successful, it might not be a workflow that is beneficial in entire Sweden.

A suggestion is to create a new classification for all links, where the most important features are located as well as the features that are not as important. These could be found, for example, by identifying the number of cars using the specific link, if the link is connecting different important roads, different important areas or similar. It is important that the reference network will remain connected and can be used as an accurate representation of a real-world transport network.

In this thesis different classifications were tested to find a classification that worked for the entire area. The one found the most suitable for the test area was when the links with the classification Role 1 and the larger roundabouts had the class zero, and remained the same throughout the generalisation, while all other links got the same classification.

One of the biggest challenges with cartographic generalisation is to make it objective and not affected by the operator. The goal is to create a generalisation that can be done again by other users. Therefore, the generalisations made by Lantmäteriet, Statens Vegvesen and the IPA generalisation by Trafikverket were studied. The generation to another level that is made by Lantmäteriet has the goal to able to use their map at different scales. Statens Vegvesen and the IPA are both used by two similar companies and therefore might have the same usage. The generalisations created by the different companies do not use the same approaches, and one significant difference is the roundabouts. The generalisation created by Lantmäteriet is collapsing all roundabouts with a diameter less than 30 m but makes all greater roundabouts to the same diameter which is 50 m. Statens Vegvesen is also keeping the roundabouts in their generalisation and specifies that it is important that the roundabout is visualised with one
single link. The IPA generalisation that is used at Trafikverket on the other hand has the restriction that every junction should be represented with a single node and therefore all roundabouts are collapsed.

In this thesis, the proposed generalisation will preserve the larger roundabouts. This is the better option for the cartographic point of view, since it is more similar to the reality. Even though some of the analyses Trafikverket are currently performing are requesting all intersections being represented with a single node. The reason why this option was chosen was because both Statens Vegvesen and Lantmäteriet is preserving these areas, and it was found important to stay close to the reality at all different levels of detail.

The goal was to investigate the possibilities and obstacles with these types of problems. Several obstacles were found already when studying similar projects at different places, such as the existing tools today might not be enough. It was clear when creating the workflow proposed in the thesis and a need for developing different tools to solve these issues were found. Some parts were manually altered instead of developing new tools, due to the time restrictions.

The need of good quality of the input data is something found very important for the tools used. There is a lot of data in the National Road Database and it was important to collect only the valid links and the right attributes to obtain a correct result. Some errors in classification and the extent of the links can occur in the database as well, and this needs to be taken care of before starting the generalisation to make sure that the result is satisfactory. This can be done by studying parts of the database and devolving functions that locate the most common error.

The study area in the thesis is limited and the workflow created might not work in other intersections that are more or less complex. But the operations used, and alterations made have shown that there are possibilities to use generalisations in the National Road Database to create new levels of detail.

There is already a request for the generation of a new level of detail at Trafikverket, both for analysing and statistics, but also for visualising the data on a map. The road level will request less data storage and it is sufficient for many analyses, where it does not matter on which carriageway the incident occurred. The linear referencing is an important part of making the reference network connected between the levels of detail and making it possible to inherit the generic features between. The referencing was found well-functioning for the small area it was tried for. When making the referencing for a more complex intersection the workflow might need to be analysed and altered to fit these areas as well.

7.1 Conclusions
The generalisation created was done partially automatic, but parts needed to be done manually. The three different areas studied had different obstacles; the parallel roads were possible to solve automatically using existing tools. The intersections were the biggest issue and is not possible to solve using the existing tools analysed in this thesis. More studying needs to be done.
The roundabouts were partially possible to be solved using the analysed tools, but additional tools need to be developed and used as well. The linear referencing was successful for the study area but needs to be tested on larger areas for validation.

The automatic generalisation to another level of detail is found possible in the near future, but parts still might need to be done manually due to the different complexities. It is possible to develop tools that identify the parts that needs to be done manual.

7.2 Further studies and recommendations

The purpose of the new level of detail need to be decided and how to visualise the different intersections and different areas, in order to create a workflow that fits the usage. This should be the first step done for implementing a new level of detail.

To create a workflow that functions for the entire transport reference network in Sweden, new functions and tools need to be developed. The generalisation for the parallel links was successful, but the other areas need more development. One other function that would be useful is the reclassification of the branches. The only type of links that should be classified as branches are the ones that does not link between two other important links. In this thesis, this reclassification was made manually but a function that studies the links nearby a branch would be necessary before removal of branches. Further studies and functions handling the different types of complex intersections are also critical for a reliable workflow.

The roundabouts need a tool that studies the links connecting to the roundabout and can identify if these links belong to the same road, and then merge them into a single feature.

In the thesis, a small area was chosen for the tests. The area had several intersections and roundabouts, but for development of functions and validation, a larger study area is needed. It is also necessary to study different parts of Sweden since there can be different solutions made, due to geological differences. When generalising a larger area, it is also necessary to use partitions to divide a large amount of data into smaller sets of features, that is more manageable.

Statens Vegvesen in Norway has a third level of detail which is the lane level, that is only used for parts of the reference network. In the future this might be useful in Sweden as well, and some of the usage might be for navigation companies that use the Swedish NVDB. These companies might use the lane level to get even more detailed navigation, where the lanes for turning will provide more information. Development of this generation would be a potential next step, if the road level is successfully implemented.

Other tools, for example the Open Source Geographic Information System QGIS could have been studies as well as a complement to the studies on ArcGIS and FME.
8. References


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Appendix 1, workflow for the linear referencing in FME
Aligning the attributes found onto the reference network.