

Student thesis series INES nr 347

Automatic Creation of Schematic Maps - A Case Study of the Railway Network at the Swedish Transport Administration

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2015
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Samanah Seyed-Shandiz (2015).
Automatic Creation of Schematic Maps - A Case Study of the Railway Network at the
Swedish Transport Administration
Master degree thesis 30 credits in Geomatics
Department of Physical Geography and Ecosystems Science, Lund University

Level: Master of Science (MSc)

Course duration: January 2015 until June 2015

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Automatic Creation of Schematic Maps - A Case Study of the Railway Network at the Swedish Transport Administration

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Master Thesis, 30 credits, in Geomatics

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Acknowledgements

I would like to express my sincere thanks to my supervisor in Lund University Lars Harrie for his helpful guidance and strong support through this degree project. Also I would like to thank my supervisors in Trafikverket, Thomas Norlin and Jenny Rasmus for their helps to work in their office and use their data and especially their experiences. They introduced me their colleagues which they also helped me a lot to understand their current system and their work. Finally, there are no words to express the deep thanks and great love I feel towards my husband, Parham and our lovely daughter, Parmiss, for their never-ending love and their attention to my involvement for which I cannot thank them enough.

Abstract

Today, one of the needs of the railway information systems is sharing the precise and exact data among varieties of stakeholders. In addition, efficient use of Geographical Information Systems (GIS) encourages the railways administrations to centralize their data and prepare an information model whose purpose is to reduce the demands associated with the transformation of the data. One such reduction of data handling is to be able to extract both geographical and schematic representations from the same database.

Currently, one difficulty which encountered by the Swedish Transport Administration (Trafikverket) is that different representations (geographical and schematic) have to be updated separately which imply larger costs and there is also a rise of inconsistency between the two representations. However, when the information model was initially developed, the schematic representation was not a requirement; subsequently, there might be some unresolved issues associated with updating these representations.

This research study is aimed to examine the information model for Trafikverket support the automatic generation of schematic maps. By studying the experiences in other European countries such as France and Holland, and doing some case studies on some central stations in Sweden, it tried to understand the ability of ArcGIS Schematic extension for automatic generation of schematic maps. In addition, this research study wants to evaluate whether the data in the current database provided by Trafikverket are suitable input for ArcGIS Schematics. The results show that Trafikverket achieved the aim of this study for automatically generation of schematic map for railway networks. It seems they can use it for their production in the real life since it makes the situations much easier for them to create the schematic maps than currently they do it manually. In addition, the evaluation of current data uses in Trafikverket shows that ArcGIS Schematics extension is matched with their data, but some improvements must be done on their data.

Keywords: GIS, ArcGIS Schematics, Schematic representation, Geographical representation, Schematic Diagram, Geometric network

Sammanfattning

Idag vill man effektivisera användningen av geografiska informationssystem (GIS), vilket uppmuntrar järnvägsförvaltningarna att centralisera sina data. Därför hämtar de både geografiska och schematiska framställningar från samma databas. Men, en svårighet som möter Trafikverket är att olika representationer (geografiska och schematiska) måste uppdateras separat, vilket innebär större kostnader och kan innebära inkonsekvens i riktigheten av dessa två representationer. Således, denna studie syftar till att undersöka hur ArcGIS Schematics automatiskt kan generera den schematiska kartan från en geografisk databas som är lämplig för järnvägsapplikationer. Dessutom utvärdera den om de data som finns i den aktuella databasen som tillhandahålls av Trafikverket kan användas för att skapa schematiska kartor i ArcGIS Schematics.

Resultaten visar att ArcGIS Schematics automatiskt kan skapa och uppdatera schematiska kartor över järnvägsnäten. Detta gör framställningen av schematiska kartor mycket lättare för Trafikverket, medan de för närvarande skapar de schematiska kartorna manuellt. Dessutom visar utvärderingen att av de data som används av Trafikverket för närvarande kan användas av ArcGIS Schematics, men vissa förbättringar måste göras på deras datamodell. En ny egenskap måste adderas till datamodellen, som definierar typer av olika delar av spår. Därför måste definieras om tåget är på en genom väg och åker direkt eller över från en divergerande väg som används för att ändra rutten och ansluta olika vägar. Dessutom, kontrollera topologiska kartor för att förbättra riktigheten i data har varit viktigt. Studien innehåller också en jämförelse med hur järnvägsoperatörer i Frankrike och Holland jobbar med schematiska kartor.

Terminology

- **Avvikande Huvudspår:** This is a deviant track which is extracted from the main track in the route.
- **BIS (BanInformationsSystem):** The Swedish Railway Network System contains the whole Swedish network with the topology of the network in the form of nodes and links.
- **Diverging:** The lines and switch legs that connect the main lines or help the driver to change the ways, therefore they act as excluded routes.
- **Kilometertal:** Kilometer post is a way for representing position and location of objects which are linked to the rail network.
- **Normal Huvudspår:** The main track is a track with possibility of highest speed and defines as the main route for trains.
- **NVDB:** It is the national road database, for information on all state, municipal and private roads in Sweden. NVDB database run by the Swedish Transport Administration in co-operation with the National Land Survey of Sweden's municipalities and county councils, forest industry and the Transport Agency.
- **SidoSpår:** The siding is used as a side path that normally trains use for parking and standing.
- **Spårnummer:** It is a characteristic of the tracks which is used for defining the number of tracks. It helps to distinguish different tracks from each other.
- **SpårVäxel:** Each leg of switches has a specific number. Therefore, this characteristic of the switches uses for defining the number of switch legs. It helps to distinguish different switch legs from each other.
- **Through:** The lines and switch legs that are located along each other and they are almost long and straight, therefore they act as main lines.

- **Trafikverket:** It is the Swedish Transport Administration, which its target is to develop the society by an accessible and environmentally sustainable transport system that supplies the passengers and industries requirements, both in road and railroad infrastructures.

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1. Introduction

1.1. Background

Today, one of the needs of the railway information systems is sharing precise and exact data among a variety of stakeholders. In addition, the use of Geographical Information Systems (GIS) encourages the railway administration to centralize their data and prepare an information model whose purpose is to reduce the demands associated with the transformation of the data (Missoumi & Nissi, 2012).

The traditional methods for presenting geographic data are maps, which organize data into pictorial and symbolic representations. Examples of such data are images, annotations, text such as names or descriptions of places, and representations of actual elements in the world by different colors and types. In this study, this kind of map is called a *geographic map*. Examples of geographic maps are city or country road maps or railroad network maps (Berendt, et al., 1998).

Another method for presenting data is schematic maps. In schematic maps, the distances and directions are not assessed in the same way as in the geographic maps (Berendt, et al., 1998). Schematic maps express only essential and important features, such as connectivity and stops on transportation maps. Therefore, they provide only linear cartograms while the length and the shape of the routes do not need to be an accurate presentation of the reality (Monmonier, 1996 & Brazile, 1998).

As representation has a key role in computational systems, two main types of representation are studied in this report. One is geographic representation whose main issue is to represent any fields that studies a certain phenomenon on, over, or under the surface of the Earth (Yuan, et al., 2004). One important application of geographic representation is the geographic representation of networks. Frequently, the geographic representation of a network fails to consider and show the information of important connectivity found in the network. In these cases, a schematic view of the network data is a suitable representation by highlighting the connectivity relationships. Therefore, the second type of representation would be schematics representation which is a

linear cartogram designed to express only important features of the network routes or transportation connectivity information. These representations are generally graphical but they can utilize haptic or auditory senses, or include elements that mix other senses with the sight. Therefore, different mixes of geographic or schematics representation phrases are included in this report (Avelar & Muller, 2000).

1.2. Statement of the Problem

In a database of railway networks, the data and information may be changed for several reasons as exemplified below (Informationsmodeller, 2013):

- since the railway system is changing in reality, the data needs to be changed and adapted accordingly, and
- sometimes the data needs to be improved to have better representation of the reality.

Recollecting the data about the features in the network would be essential to reuse the relationship between the geometry data in the system. Improvements in the quality of the data geometry or changes of the railroad designations continuously require changing and improving the data in the database, which causes double updating in the databases: one for the geographical representations and one for the schematic representation (Informationsmodeller, 2013).

Currently, one difficulty encountered by the Swedish Transport Administration (Trafikverket) is that different representations (geographical and schematic) have to be updated separately imposing large costs and creating the possibility of inconsistency in the accuracy of these two representations. This study examines the relevant studies by executing fact-finding on the Internet and interviews with railway administrations and companies in Europe. In addition, the study applies the prototyping method in order to address the research objectives.

1.3. Research Objectives

The main objective of this study is to investigate the link between schematic and geographic representations of the railway network. The specific objectives of this study are:

- Evaluate the current data model at Trafikverket in Sweden to determine if it is a suitable input for automatic generation of schematic maps.
- Study algorithms for creating schematic maps.
- Examine ArcGIS Schematics extension for automatically generated schematic mapping from a geographical database that is suitable for railway applications.
- Explore whether the ArcGIS Schematics meets the requirements of the railway network which are provided by Trafikverket.
- Investigate the use of ArcGIS Schematics in other European railway authorities.

1.4. Methodology

This project starts with a basic study about the current system for handling schematic maps at Trafikverket; in this study their problems and their demands are identified. Then a study is performed about schematic mapping theory and the ArcGIS Schematics extension. The initial feasibility study by reviewing the applications of ArcGIS Schematics for services and transportation is done. In addition, by interviewing other Railroad Administrations in Europe, their experiences of applying ArcGIS Schematics extension are investigated. After that, the current information model at Trafikverket is evaluated for use in ArcGIS Schematics. After testing the data for Avesta Krylbo central station and editing and improving the data, a methodology for creating satisfying schematic maps was obtained. This process also identifies possible shortcomings in the current information model at Trafikverket. For verification the final result, the schematic maps for two other central stations (Lund and Malmö) are created. Finally, according to the obtained results, the identified objectives of this project are evaluated. Figure 1.1 demonstrates the outline of the whole project.

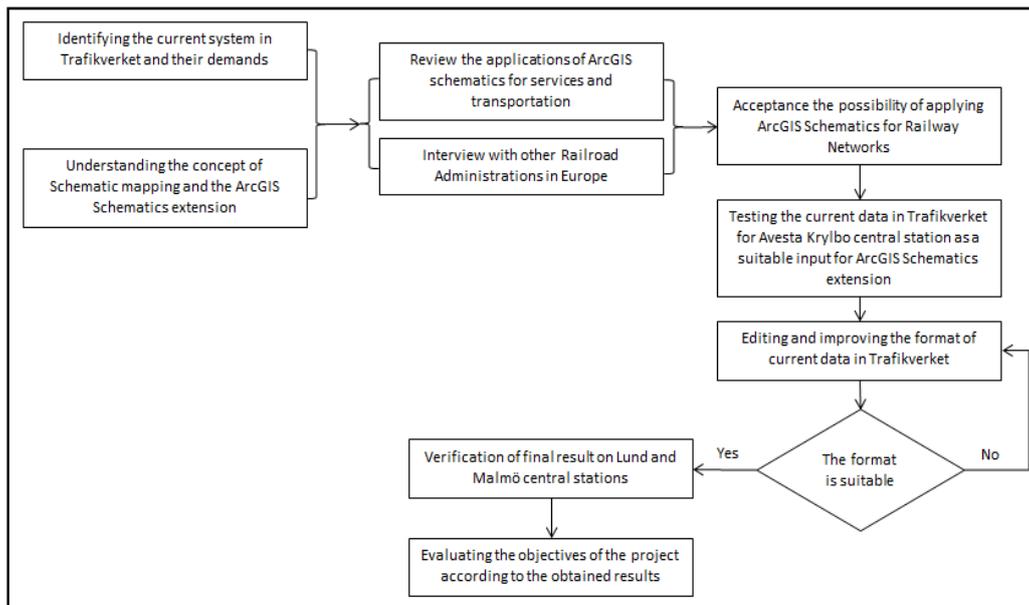


Figure 1-1: The Methodology and outlines of this project.

1.5. Scope and Limitations

The scope of this study is limited to the schematic representation of the geographical railway network at Trafikverket. This study starts with general information about Trafikverket and railroad information and schematic mapping. Later, the methods used in some countries in Europe are studied, and finally it follows the more restricted practical part which it is limited to the ArcGIS Schematic. To end with, the research is focused on the capabilities of the ArcGIS schematics on automatically updating of the schematic data due to the changes in the geographical data.

This study aims to generalize findings about the use of schematic mapping for railroad information. However, the practical part of the study is limited to only the ArcGIS program. In addition, the results were tested only on some of the railway central stations in Sweden.

1.6. The Thesis Outline

Chapter 1 contains the Introduction. The reader is introduced to the background of the study and the problem statement as well as the research

objectives. Also the main question of the research is defined along with determining the scope and limitations.

In chapter 2, some information about Trafikverket and railroad information is provided. This chapter elaborates on the Swedish railway network system (BIS) in Trafikverket, the Swedish Standard (SS 63 70 04-1:2006), and the New Information Model Transport Network – Road and Railway (Informationmodeller). And finally, it reviews the current process for creating schematic maps at Trafikverket.

In chapter 3, the concept of Schematic mapping is explained. Moreover, different types of schematic diagrams, as well as the characteristics of schematic mapping are introduced. In addition, different algorithms for creating the schematic maps are investigated. Furthermore, the advantages and disadvantages involved in using the schematic maps are detailed.

Chapter 4 presents the theory and application of schematic mapping in ArcGIS. Especially information is provided on the algorithms and parameters for creating the schematic maps are described. Different elements in the ArcGIS Schematics are also introduced. In this chapter, the algorithms are estimated for creating schematic maps in ArcGIS according to the theoretical algorithms introduced in chapter 3. Hence, the functionality of the applications on the market for schematic representation of a railway network and other related experiences are described.

Chapter 5 contains an outlook on the use of schematic maps at other railroad administrations and companies in Europe.

In chapter 6, the study area and data used in the practical part of this study are introduced and the methodology for applying the model is described. Finally, the ArcGIS Schematics is configured for a pilot study at Trafikverket, in Avesta Krylbo, Lund and Malmö central stations.

In chapter 7, the results related to applying the model along with the layout and features of the model are presented. Furthermore, the ArcGIS Schematics is evaluated by prototyping. The current rules and data in creating schematic

mapping in Trafikverket are evaluated and they are compared with the information (rules and data) in the ArcGIS Schematics model.

The thesis concludes with a discussion in chapter 8 and concluding remarks in chapter 9. In the latter chapter, suggestions for further improving and developing the model in Trafikverket are provided.

2. Swedish Transport Administration (Trafikverket)

Trafikverket aims to provide society with accessible and environmentally sustainable transport system that meets the passengers' and industries' requirements, both with road and railroad infrastructures. The transport policy goals through which they guarantee a socio-economically effective transport supply system for citizens are divided into two types: functional goals and consideration goals. The functional goals are about creating availability for travel and transportation, and the consideration goals are about safety, the environment and health (Sarin, 2014).

The predecessors of Trafikverket were Vägverket (the Swedish Road Administration) and Banverket (the Swedish Rail Administration); they joined in the beginning of 2010. Based on the data and information retrieved in September 2013, Trafikverket has around 6,300 employees who work in different areas such as traffic control on the roads and railways, community planning and negotiation and survey, IT-work, technical survey and development, inspection and supervision, shipping, architectural and infrastructure design, as well as production planning and production management. The head office is in Borlänge, and it leads six regions with regional centres in Kristianstad (South), Gothenburg (West), Eskilstuna (East), Stockholm (Stockholm), Gävle (Central) and Luleå (North) (Sarin, 2014).

At Trafikverket, a wide network of diverse and combined databases is available and gathers information about the railway network. Stakeholders can access these data according to their needs and demands to carry out outsourced activities such as maintenance, performing studies, designing improvements, and the like (Morant, 2014). The main architecture of the whole railway organization is accomplished and managed by an asset management system with many dependencies on other systems. The asset management system allows users to see which items compose a section and design the railroad's signaling, track components, the power supply, and so forth. By looking for a specific item in this database, one can see what has been installed there and what inspections and checks have been performed. This system is called BanInformationsSystemet

(BIS). BIS represents current train locating in the railway network. There is no full history, nor is there the option to view future locating (Ekström & Gabrielsson, 2012). In January each year, the database is archived and by comparing the archived data and information, some important changes are detected but they are not presented in detail (Banverket, 2008).

Since 2013, Trafikverket has developed and published a new information model which is called Informationsmodeller (In English: The Information Model Transport Network – Road and Railway). In order to provide a background to this model, the BanInformationsSystemet (BIS), and the Swedish Standard: SS 63 70 04-1:2006 (Geographic information – Road and Railway Networks) are introduced briefly in the following sections.

2.1. The Swedish Railway Network System (BIS)

The Swedish Railway Network System (BIS) (in Swedish, BanInformationsSystem) contains the whole Swedish network with the topology of the network in the form of nodes and links. The switches and buffers are examples of the nodes and groove and links between them are forming links. The geographical description of the net, in the form of nodes and links, is coordinates in the geodetic reference system SWEREF 99 TM. The Swedish railway network constitutes one of the railway administration activities and unified models in the form of a linear reference system objects associated with the track links and divisions of the railway network. Figure 2.1 illustrates the view of BIS system related to geographic and schematic representations.

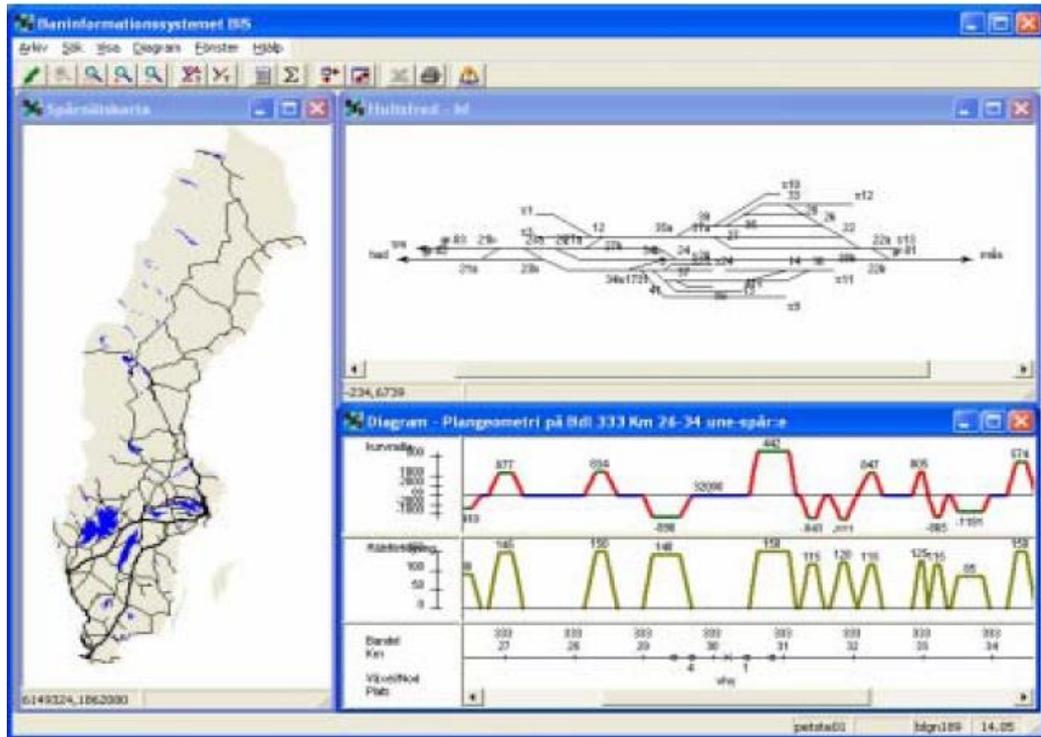
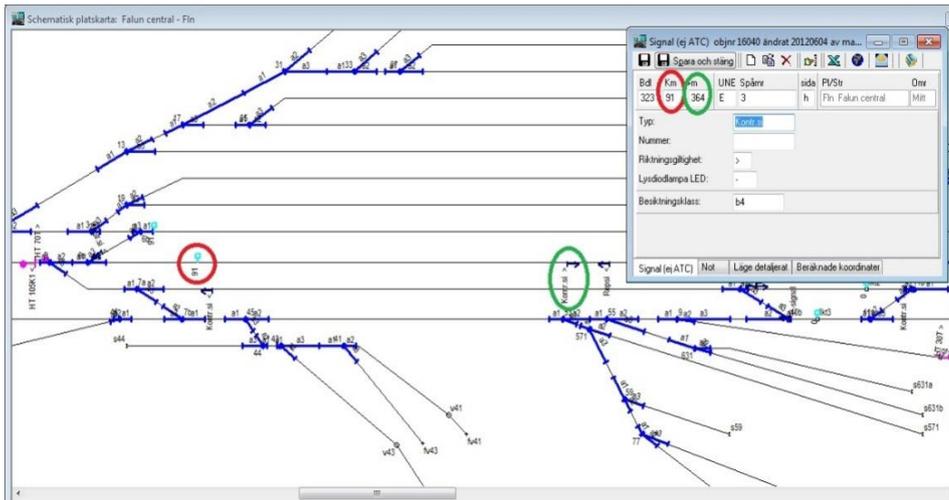


Figure 2-1: The BIS system view.
From: (BIS-handbok, 2007), p. 1

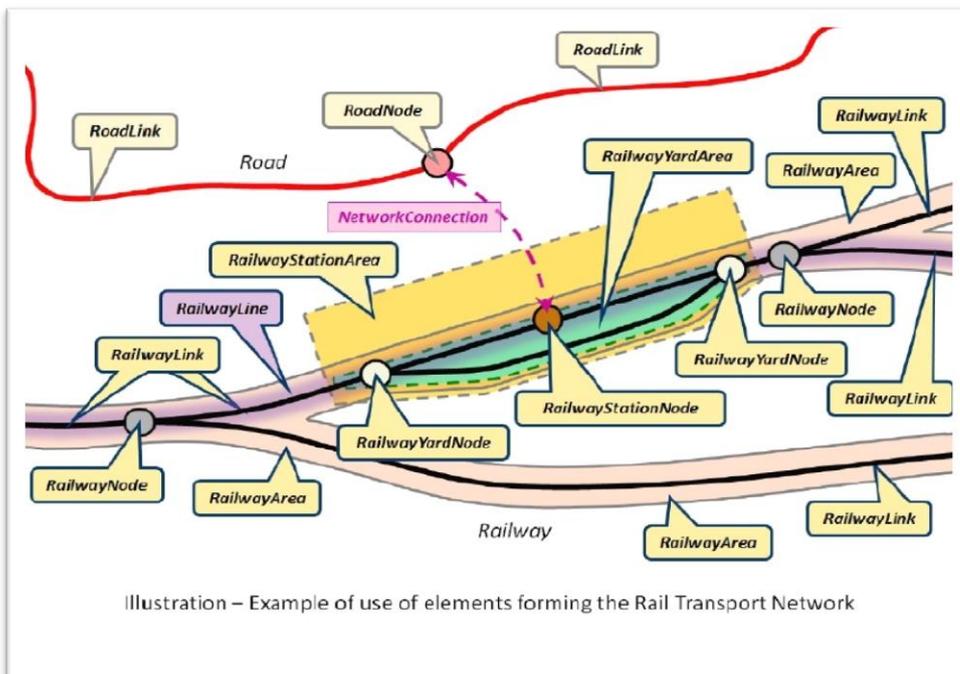
In BIS, there is a system for positioning which is called *Kilometertal* (In English: Kilometer posts) and is widely used in field operations. *Kilometertal* is a way for representing the position and location of an object which is linked to the rail network. It is specified with (km + m) reference where km corresponds to the distance from the *kilometertal* and m corresponds to the number of the meters after the *kilometertal*. The direction corresponds to the length measurement direction. Therefore, *kilometertal* report the kilometer measurements related to most items and classifications. The vast majority of objects are measured in relation to *kilometertal*. For example, figure 2-2 exhibits a *kilometertal* located in km 91 (red circle), and an object located 364m after the *kilometertal* (green circle); thus it can be seen in the property of the object that the location of the object is (km91 + 364m).



**Figure 2-2: Kilometertal. Extension of object X to the network with reference to the kilometertal. Kilometertal: km 91 + 364m.
From: BIS database**

- Basic Network Structure in BIS

A railway network has a basic network structure which includes the topology, network linkage mechanism and spatial (location, shape) descriptions. The network is a set of interconnected linear elements (links), which are interconnected by nodes. Both the location and shape of the elements of the network are described by coordinates. Figure 2-3 shows the elements that form a transport network.



**Figure 2-3: Overview of the main Rail Transport Networks objects.
From: (Nissi & Missoumi, 2012), p. 8**

There is a need to consider the railroad with variety levels of details for different purposes and applications. The data product includes two levels of details, namely the micro and macro levels. The links at the micro level consists of the track links with start and end in nodes. This detailed description of the network is called BIS reference system. The links at the macro level are represented by the connection of two adjacent interchanges. This is indeed an automatic generalization and representation of possible double tracks or more tracks into a track link. The nodes are generalized to the midpoint of the current traffic sites representing the start and end of the connection. The generalization to the macro level is accomplished in order to represent the objects on a small scale map while it does not impose any restrictions on the registration of the objects in that all the items are recorded at the micro level.

Nodes are points representing a location where the tracks of the vehicles drivability changes through the switches or where the tracks end. A node can also be an operational site boundary separating the track function when certain safety rules apply in the operation site boundary and beyond. At the macro level, the nodes in the middle of intersections can be a type of operation, direction and line location. The nodes at the micro level must always be within an interchange while in the macro level they are automatically generalized to correspond to the position of the spot in the middle of line and to adopt the traffic site name.

The track link is a section on the railway which is chosen to represent the railroad between two nodes. For each track link in the model, the data are stored in the form of start to end. It needs to be highlighted that the track link is a link at the micro level. A BIS connection is a link at the macro level which represents the distance between two traffic areas at the centers. Only one BIS connection exists even if there are several parallel tracks in reality. Figure 2-4 shows railroad information in micro and macro level.

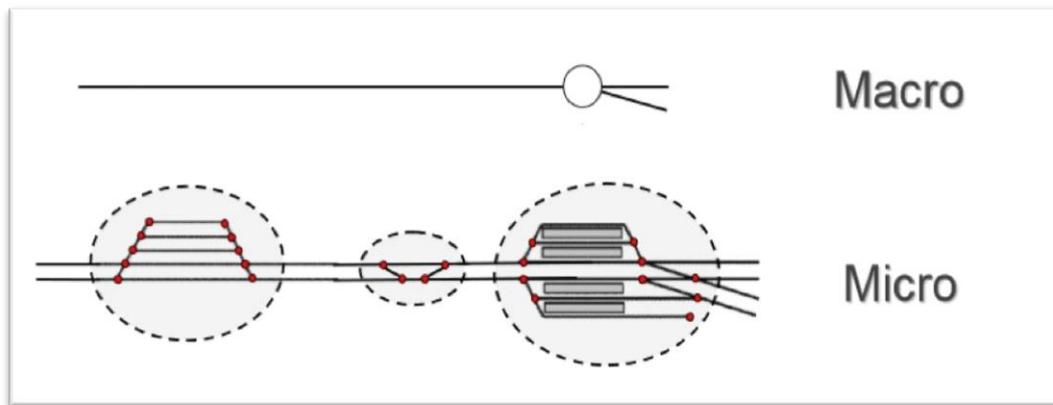


Figure 2-4: Railroad information in micro and macro level.

From (UIC, 2013), p. 22

To describe how railways are linked in the model, their topology utilizes different parameters such as nodes, track links, directions, sides and connections. The topology describes which nodes belong to the links, how vehicles can change tracks in nodes, where each object is located in the network, if the items have point or line extensions, and if the objects are located on the side of the track. These descriptions are clearer than a map. On the map, it assumes that it is possible to get from a track link to another, but there may be barriers that are of logical nature and they are not visible in the map; for example, the connections that are not executable in the points. The topology clarifies logical relationships between the nodes, links and items (Ekström & Gabrielsson, 2012).

- **Network Connection in BIS**

An object is itself composed of two parts: a description of the item and specification of its location in the network. The description is made with one or more attributes. The position is accomplished by the object which is given a spread on the network and is linked to the rail network with the link identity and distance from the previous node in the direction of link (link mode).

- **Geographical Coordinate System in BIS**

Both track links and nodes have coordinates in the geodetic reference system SWEREF 99 TM which is the Swedish realization of ETRS89. The connections in BIS are coordinated in terms of a generalized comparison with the underlying track links (Ekström & Gabrielsson, 2012).

- **Linear Reference System in BIS**

The Swedish railway network organizes one of the complex administration activities and unified models in the form of a linear reference system (LRS); it uses kilometertal for specifying the location of objects. The objects are associated with the track links and divisions of the railway network. Identities and positions of the nodes/links are the basis of the reference system along with the allowed connections for the tracks to and from the nodes. Using a linear reference system gets the position of an object relative to a line in the linear reference system. LRS has been known, accepted and sustained over the time and kilometertal works according to this linear reference system (Ekström & Gabrielsson, 2012).

- **Schematic Representation in BIS**

Schematic maps have a long tradition in railway information systems. Trafikverket implemented a geographical representation for the whole country on micro level, along with the schematic presentation for each station separately. They use schematic maps for the time table, the position of trains (traffic information) and for subways maps, and use geographic map for the society plan, for changing among different kinds of ways such as roads, railroads and bicycle roads, for houses' locations regarding the railroads, for defining the suitable sound distance from the railroads to the houses and for many other different information.

Currently, BIS stores both geographical and schematic representations. In this database, the specific location of each item and its model are defined. The information in this database is a source for different activities such as signal design, updating and maintenance, planning and analyzes of the traffic,

preparation of various kinds of visualizations and reports, etc. Furthermore, it defines which items arrange a section of the railroad such as signaling or components of a track (Morant, 2014 & Trafikverket, 2013).

Therefore, the purpose of BIS is to gather information about the assets in a single railway system so that all information should be easily accessible to all. BIS is thus a system to search for information about the network and objects (assets, etc.) which are connected to the network. The related track information do not just refer to physical systems such as rails, switches, curves, bridges, level crossings, signals, etc., but also other items such as defining the track direction, sleeper inspections etc. can determine the position (BIS-handbok, 2007). In this system, the railway network has the ability to use kilometetal. In addition, it uses distance from those posts for positioning, and describes the probable ways to travel through switches. Therefore, in this system, the schematic geometry on the nodes and links is described. The schematic geometry is mainly used for making the graphical representations of a network readable (Informationsmodell, 2013).

2.2. Swedish Standard: SS 63 70 04-1:2006 Geographic Information – Road and Railway Networks

The Concept Model and Application Schema

The principle of this standard is to enable information exchange between the operators. The standard actually consists of three standards: first for defining how a network must be described, second for generic feature model and third for describing the data exchange between actors. The shape of the road and railway networks is considered as the basis of this standard. In this standard, a network model is described by the specific object information such as a road between X-town and Y-city, but it also represents the basic information on how the other information should be related to it. It also supports different ways of usage as well as being used by different user categories. Supporting the data exchange in this standard has influenced the application schema with a certain extent, and also in

some features of the model. For using this standard, several documents are necessary. For the dated references, the cited version is only valid. Contrarily, for the undated references, the latest version is valid.

The content and structure for a dataset is identified by the application schema. Its purpose is to set up and define a common interpretation of the data. This application is not adjusted by any special hardware or software. The concept schema language in the application schema is UML (Unified Modeling Language) which is a graphical modeling language. This application is described for each part/package with a variety of class diagrams and class descriptions (SS637004, 2006).

UML is a general modeling language in software engineering. Its basic level provides a set of graphic to visual the objects model. UML language defines nine different types of diagrams: class, object, use case, sequence, collaboration, state chart, activity, component, and deployment. Some parts of this modeling language are described briefly in Appendix 1. In a network model, the class diagrams are the most popular diagrams which are used for positioning objects. They describe the static structure of a system (SmartDraw, 2014).

Although this standard is not implemented in BIS, but it is used when building the multimodal database is needed, such as TNE (an ESRI geodatabase) in Trafikverket. The data of this geodatabase was used in case study of my work.

2.3. The Information Model Transport Network - Road and Railway

The information model is defined to manage the demands of Trafikverket's external actors. In addition, it must meet the compulsory requirements of Trafikverket, and also the requirements of the Swedish Standard (SS 637004). The information model has many similarities with Swedish standard described above and it has been implemented for handling roads in NVDB, such as the intermodal transfer nodes and managing the multiple levels of the network details (Informationsmodeller, 2013).

- **The Reference System in the Information Model**

The aim of the transport network as a reference system is defining where features such as equipment, construction properties, etc. appropriately connect to the network. Thus it is possible to provide the topological relationships between different objects in the network such as borders and intersects. Another aim of the transport network as a reference system is defining the timeline as an essential part for the net and the features. This means that it can be possible to go back in time to see how the transport net was configured at any given moment, this is a huge improvement compared to BIS. By creating a relationship between the elements in the reference system (transport network), the features are connected to the reference system. In other words, the features do not need to have any information about their positions; hence, they obtain their information from the reference system via their relations.

Using transport network as a reference system brings various advantages; it makes it easy to discover all the features that affect a definite part of the network. The reference system is meant for helping this purpose and it must also have the ability to provide a number of services or functions to support, e.g.:

- Connecting features to the reference system.
- Providing basic data such as geometry, and the type of the roads.
- Establishing a transformation between different reference systems, like between a linear reference system which is defined by Trafikverket and it is called *kilometer post* and SWEREF 99TM.
- Selecting geographic collection such as all network components within a service area.
- Selecting based on, for example, type of the road or tracks, etc.
- Mapping in different forms of services such as in the form of a web map.

According to the above services, transport network as a reference system contains the following elements:

- The reference network, roads, and rails. The thought of the reference network describes:

- Where all the road and rail routes are located in a network and how they are connected to each other.
 - That the network should form and organize in itself the reference system which might connect and reference other features.
 - That the networks should have ability to cover different types of networks which are available in each mode of transport, such as car, bike, and rail, etc.
- The generic model for the preparation and maintenance of other features that are connected to the reference system.
- The service interfaces, which is included in the total vision for future architecture.

The general level of relations between different parts of the information model along with the relationship between the transport network (road and rail) and the features that are connected to the network are illustrated in figure 2-5.

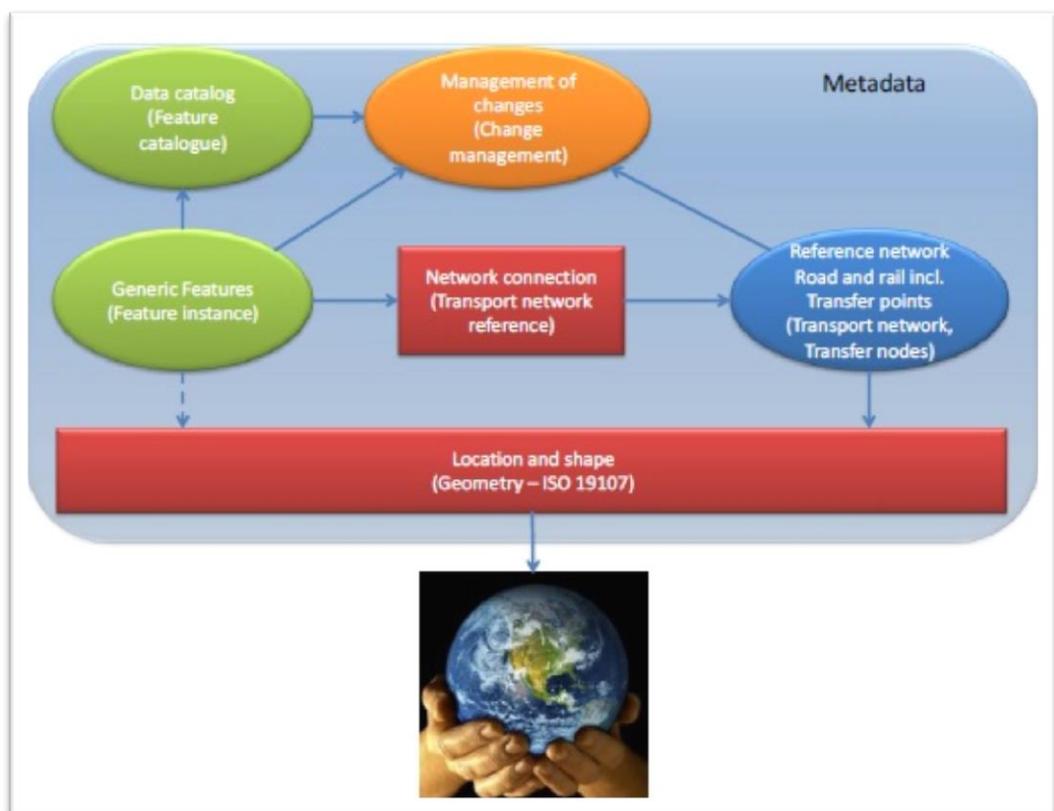


Figure 2-5: Relationship between transport networks, operating data and geography.
 From: (Informationsmodeller, 2013), p. 8

In this model, the *reference network (road and rail)* describes the main properties of the actual network, such as topology, geometry and the time dimension. The *generic features* describe a logical or physical connection of different objects or events to the network. The *change management* topic describes the changes in data, such as what changes happened in the network, when, why and by whom. The *metadata* provides information for all data that the internal and external users need. The ability of *metadata* is to define what data are available and if these data are used in a certain context or not.

The require of business data to this information model, causes definitely that the model must be in general, in such a way that different types of features can be added, deleted or changed easily without any development in the system. The model also should be able to handle and manage objects, events and partitions or attributes in the same way. It means that the way that the features are defined in this model is generic and type independent (Informationsmodeller, 2013).

- **Information Model**

The purpose of the model is to cover the total requirements and to supply for the following areas (Informationsmodeller, 2013):

- transport network as a reference network
- network connection
- generic model for features
- change management.

- **Overview of Different Packages of the Model**

Using different packages in this model helps to divide the model into several logical topics, where each topic covers a specific area of information. Also, it is a way to check the dependencies between the components of different packages. Figure 2-6 shows all packages that are used in this information model and their interdependencies.

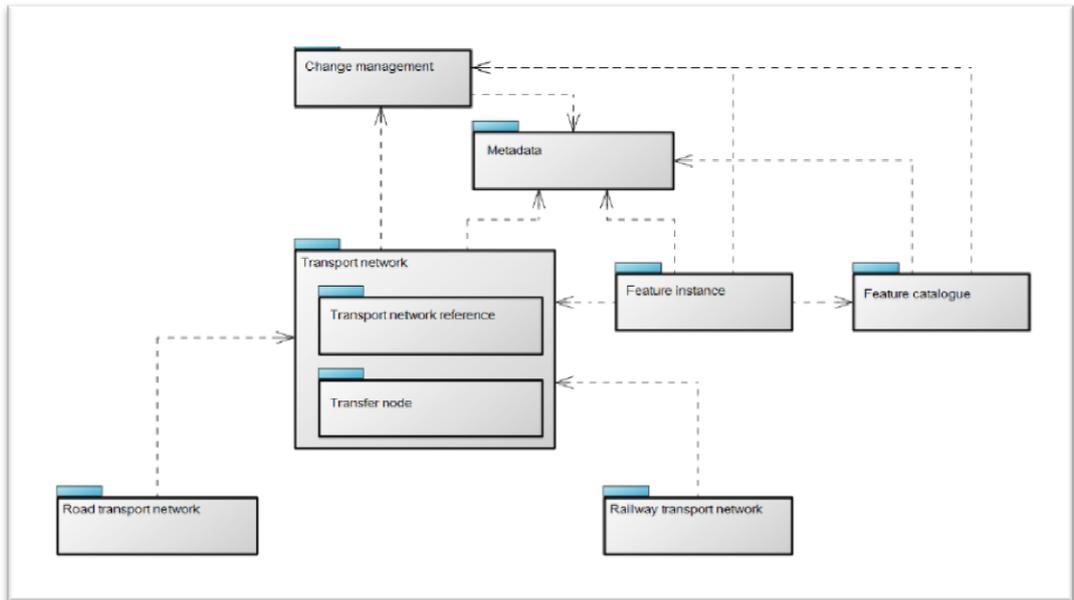


Figure 2-6: Package structure.

From: (Informationsmodeller, 2013), p. 19

The specified packages in figure 2-6 are as follows:

- *Transport network*: for describing the general aspects of the network.
- *Transport network reference*: for providing a model for network connection.
- *Feature instance and Feature catalogue*: for describing a basic model for features that are connected to the network.
- *Road transport network*: for describing specific features of road networks according to the general network model.
- *Railway transport network*: for describing specific features of railway networks according to the general network model.
- *Change management*: for describing information that the model needs to update.
- *Metadata*: for describing properties of data, such as quality declarations.

Each package is demonstrated by some figures in UML format diagrams. The reason for creating multiple diagrams is to make the model easier to read and understand. For connecting different diagrams to each other, same class occurs in several diagrams. Some of more related packages to the topic of this thesis are briefly described below. They are Transport network package, Transport network reference package and Railway transport network package.

- Package Transport Network

The transport network package introduces a basic network structure. This model describes transport network as a set of interconnected linear elements or links (Links/TransportLink). The links are also interconnected via nodes (TransportNode). Position and shape of these elements in the network are described by geometric lines and points. For connecting different features to the elements, a linear element also defines which is called TransportLinkSequence or RefLinkPart. The description of how different features are linked to the network is described in the Transport Network Reference package.

Figure 2-7 describes different classes that create the basic network structure. This figure shows that class TransportNetworkElement is a base class for different types of network elements in a network. Also, figure 2-8 represents different types of network elements that can be presented in a network.

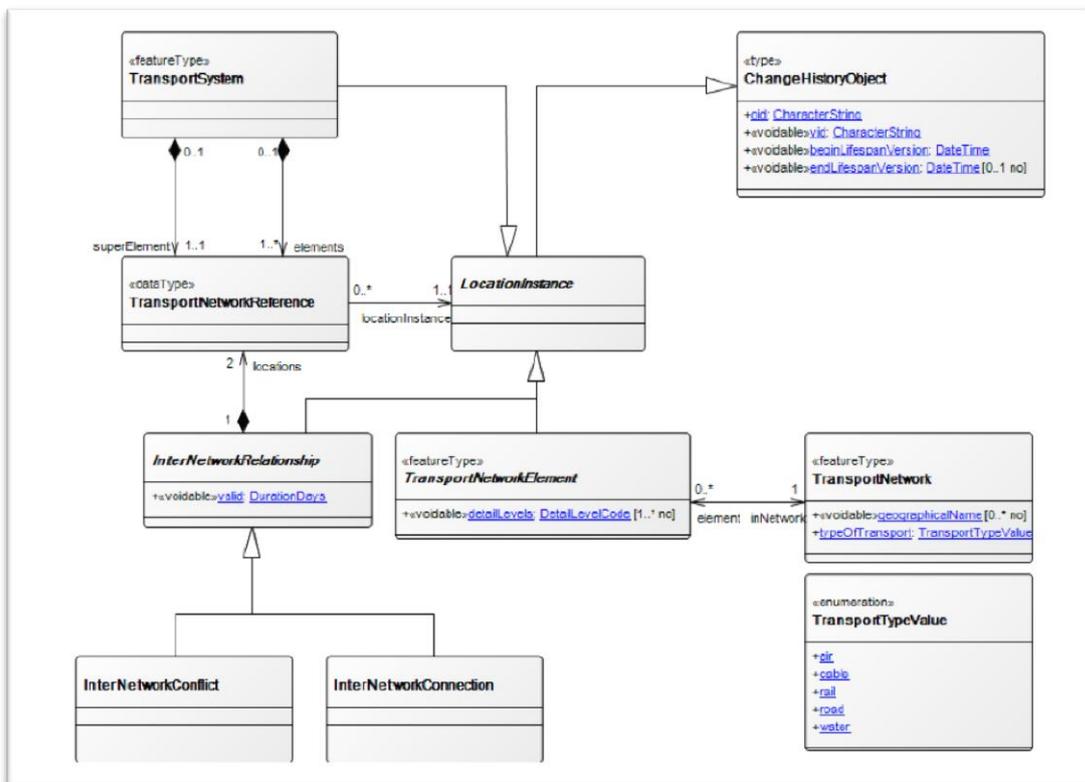


Figure 2-7: Overall structure of transport network.

From: (Informationsmodeller, 2013), p. 22

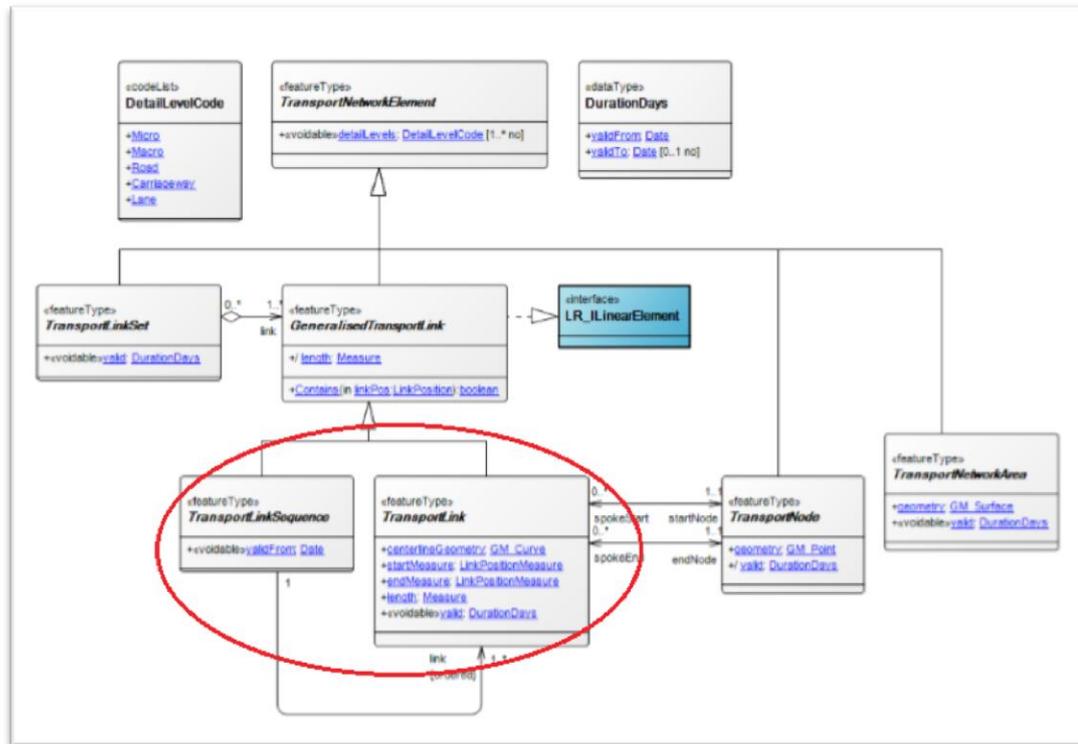


Figure 2-8: The different types of network elements.

From: (Informationsmodeller, 2013), p. 23

Generally, classes TransportLink, TransportLinkSequence and TransportNode are used for describing links and nodes. Nodes describe possible place for different routes in a network, such as switches. But, for describing how the travel can be possible in the network, the links connect each two nodes. Theoretically, each node can have unlimited incoming and outgoing links, but practically, e.g. in switches, there are some physical limitations. Since, links and nodes have geometry, therefore there is a possibility that network elements are linked with geography. These classes are explained in the following, but the rest of classes are described in Appendix 2.

TransportNode: It is a type of network elements which is used for representing a specific position in the network. A node is an abstract base class which always locates at the beginning or end of a link.

TransportLink / RefLinkPart: It is a type of linear network element which is used for connecting two nodes. It is an abstract base class. The direction of a link is

always positive from its start node to its end node which it is consistent with its geometry direction.

TransportLinkSequence / RefLink: It is also a type of linear transport network element which is used for describing a sequence of transport link. This element is an abstract base class. A link sequence can pass through one or more nodes, but if two links are connected to a node, one link should income and the other one should go out.

- Package Transport Network References:

Transport network references package describes specific classes that connect data to the reference network. In this package, concrete classes are used for describing locations of the features that are related to the network. There are different methods for network connection as follows:

- connection to random position of objects (LocationInstance)
- connection between the whole/part of a linear element (GeneralisedTransportLink)
- connection to a set of linear elements (LinkSet)
- connection to a node (TransportNode)
- connection to a surface (TransportNetworkArea)
- connection to different network connections, such as network transition or network conflict (InterNetworkConnection/InterNetworkConflict).

Figure 2-9 shows a basic type of the transport network reference package, but the detail of different classes in this package are described in Appendix 3.

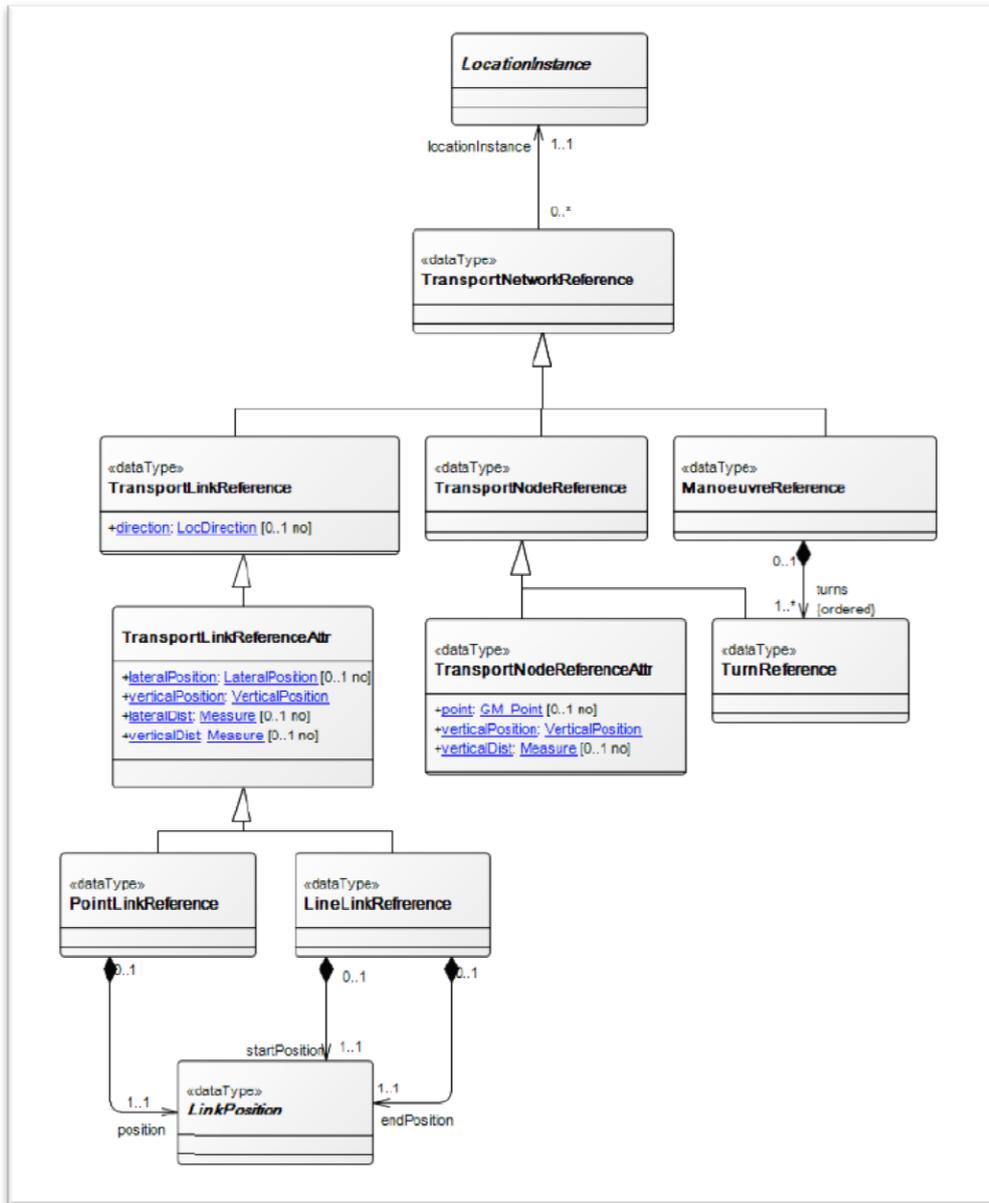


Figure 2-9: Transport network reference, basic type.

From: (Informationsmodeller, 2013), p. 53

- Package Railway Transport Network

The basic model of network and the network connection fulfill the basic requirements and demands for the railway network. Therefore, a few classes are indicated in this model while they specify the general classes regarding the type of railway transportation. As figure 2-10 shows, the main classes in the railway transport network (RailwayLinkSet, RailwayLinkSequence, RailwayLink, RailwayNode) are respectively connected to the TransportLinkSet,

The most significant supplement to the railway networks as a general transport network is the facility to use kilometer posts (kilometertal). This is a secondary linear reference system in compare to the primary linear reference system which is still measures the true distance along link. In addition, the distances from the switches which necessitate the trains to change their path or travel through these locations are described. The most important feature of the information model is that there is an opportunity in this model to define the schematic geometry on the node and the link level in addition to describing the normal geometry. Schematic geometry is used mainly to make readable the graphical representations of a complex network, such as the operation station. Figure 2-11 represents a type of referent for kilometer posts.

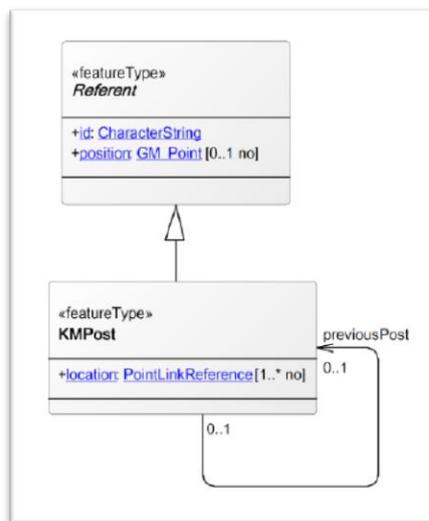


Figure 2-11: KMPPost – type of referent for kilometer posts.

From: (Informationsmodeller, 2013), p. 88

- *KMPPost*: The kilometer post class is used for describing a Referent type corresponding to kilometer posts on railways. The objects of this class are used as referents for location data with LinkPositionReferent for indicating the position relative to the kilometer reference system.

The PointLinkReference is used for describing the link position of kilometer posts, as indication of the network element (link,) as well as LinkPositionDist for indicating the distance from the start node on the link where kilometer post exist. Each kilometer post has point reference contrary to each link where it can be used (parallel tracks), therefore a KMPPost can have one to many (1..*) locations.

2.4. Current Process for Generating Schematic Maps in Trafikverket

Trafikverket currently creates schematic maps in BIS. The steps for generating the schematic map are summarized below:

- The person who wants create or edit a schematic map (called designer below) must get some drawings from the reality or some documents and information from consultants. These documents can be a schematic map as in word or pdf format or on the paper, the instruction guidance, or a geographic map file. After creating schematic maps, some information in all these documents are important for creating geographic maps. These information include clear description about the coordinates of the tracks, the switches, the kilometertal, signaling and so on.
- After the designers have gathered documents, they have to create all nodes and links such as tracks, switches and signaling manually in BIS. It means they construct and translate the geographic drawing and documents in BIS to the schematic view, and decide how it must look like; in other words, BIS could not generate the schematic map itself and user draws the schematic map according to the position and the shape of the station. Then the designers must send a report to the BIS-Administrator and wait for one day.
- In the next day, after the new lines and nodes are located in the database (by BIS-Administrator), the data is exported to BIS System and the user can apply them.
- BIS users have to define the new coordinates for all objects and then create the geographic map. Hence, having performed these processing, they can have at first the schematic map and then the geographic map of new objects.

For creating the schematic maps in BIS, there is not any specific rule or guidelines of how the schematic maps should look like. By looking to different schematic maps in BIS, it can be seen that the break point angles can be 45° , or the space between lines is about 100 pixels. But this space can be varying from 0 to 100 pixels. In addition, a line can be broken in several points while another line can have no break point. So in BIS, the personal style of the designers affects the shape of the schematic maps.

3. Concepts of Schematic Mapping

One method for presenting data is to create schematic maps in which the distances and directions are not assessed in the same way as in the geographic maps (Berendt, et al., 1998). Since schematic maps express only the essential and important features, they only have linear cartograms which are designed for the intended purpose (Monmonier, 1996). Because the essential topological information such as the connectivity and stops on the transportation maps is preserved, the length and the shape of the routes in the schematic maps do not need to be accurate as to reality (Monmonier, 1996 & Brazile, 1998).

Sometimes, in a geographic view of a network, the important connectivity information is hidden. Thus, by creating a schematic diagram of the network data, the information relating to the representation is provided, in a way that the relationships of the connectivity are highlighted (Yates & Humphreys, 1998).

3.1. Types of Schematic Maps

There are several types of schematic representations of a network. The geographic representation of the network is regularly used as a starting point for producing schematic data. High accuracy of geographic and topological information is essential for calculating the exact relationship between the objects. The schematic map of a network is mainly focused on representing the relationship of the topological connectivity between the linear features. This type of schematic map is called geo-schematic representation.

Geo-schematic representation of a network maintains some of their spatial accuracies, but allows independency for modifying the networks to allow the data to be displayed more informatively (figure 3-1). The nodes in a network are kept in their original geographic locations or almost close to such locations, and the linear features are exploded, dragged, or changed as required.

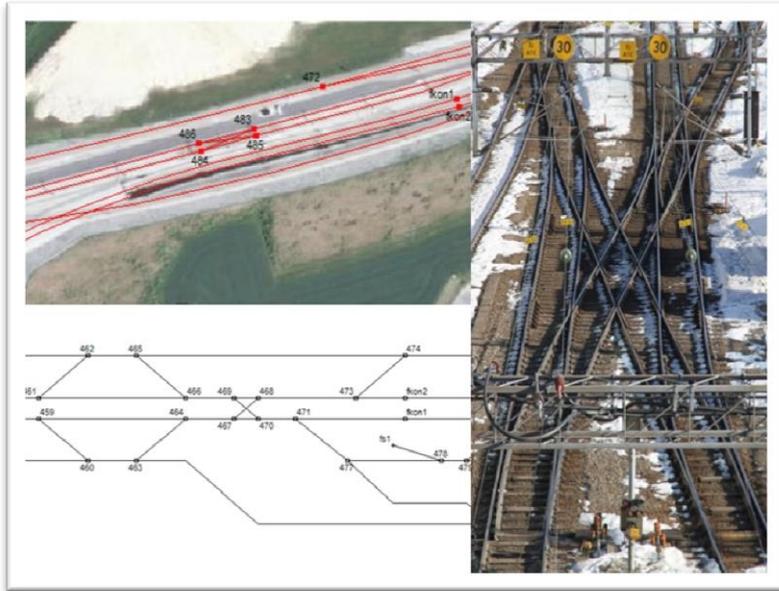


Figure 3-1: Views of the geographic and geo-schematic representations beside the real life of the railway.
From: (Rassmus, 2014), p. 6

Another type of representation is called the purely schematic representation wherein the geographic location of nodes is not used for positioning and locating a node in the schematic representation. The nodes are located only because the connectivity. Figure 3-2 shows the nodes' positions in the classic metro map in Washington in comparison with the spatial map. As it is defined in this picture, the exact geographical positions of the nodes (stations) are displaced but the relative positions between the nodes are mostly retained.

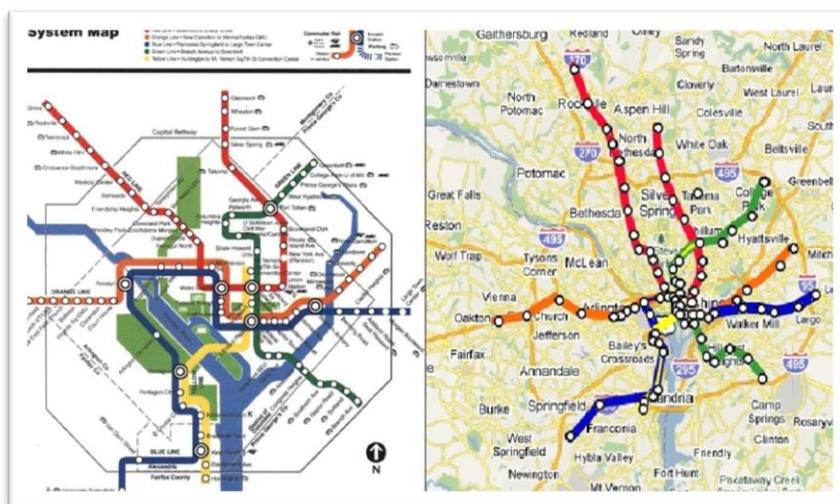


Figure 3-2: Washington Metro Map (Classic and Spatial Map).
From: (WashingtonMetropolitanAreaTransitAuthority, 2006)

3.2. Characteristics of Schematic Maps

Routes in schematic maps are commonly drawn straight. The lines have different directions with fixed and stylized angles, such as 45° and 90°, or 30°, 60° and 90°. Some schematic maps have only simplified lines with arbitrary directions while the lines in the network maps with overlapping routes are separated by a minimum readability distance. This distance can be zero or a constant value for the map (Avelar & Muller, 2000).

Connectivity and relationships are important parameters for managing and observing the networks. By representing the connectivity, different varieties of information are clarified while they can produce diagrams that express how objects are related. The main types of network are physical networks, such as communication, transportation, water supply and wastewater, and social networks such as health, agriculture, finance, and homeland security. Consequently, according to the needs, connectivity can perform in different manners (Esri, 2013).

3.3. Related Studies of Schematic Maps

Hochmair (2009) analyzed how detailed network information in the map of public transportation affects applied proxy principles when the fastest route in an urban transportation network is to be planned. In addition, he examined whether a map reader is affected by the detailed network information on the schematic maps when he tried to find the fastest route in the process of trip planning. Thus, he compared the schematic map and the maps with detailed information, departure times, and the current transit vehicle's positions. He applied five types of maps in his study; four of them were based on a schematic network map while their detailed information was different. The fifth map was a reference map which approximately showed the correct spatial layout and view of the network. This map also provided the same information as in the schematic map (Hochmair, 2009).

Hochmair (2009) argued that in public transportation systems, the schematic maps help users to direct their attentions on the decision points and routes;

henceforth, these points and routes can be derived more easily than by using general maps. Finally, Hochmair (2009) assessed the effect of time related to the observations in a map for planning the fastest route in an urban transit network, indicating that the headway information increases the efficiency of planning for unfamiliar users in comparison with using the traditional schematic maps (Hochmair, 2009).

Weihua (2008) analyzed multiple restrictions for designing cartographic map of schematic road network. He set up a number of quantitative criteria for displacing a new road network by a simplification method with progressive selection. In addition, he researched topological examination methods for road networks. In this research, Weihua (2008) described that since schematic drawing of route directions was one of the most popular graphical communication forms, he focused more on traditional mapping and on automated mapping as well as the GIS (Weihua, et al., 2008).

The appearance of miniature and small technologies, together with the extensive availability of products with digital geographic data has led to an increase in the demand for generalizing the automated map, particularly in the mobile GIS applications. Ware et al. (2006) presented an algorithm for automatically generating the schematic maps from a large scale of network data, highlighting that the schematic maps are useful for presenting routes and finding ways. In addition, the components used by Ware et al. (2006) for the mobile GIS included a positioning system such as GPS, a manual/ small computer and a communication network with GIS performing as the support (Ware, et al., 2006).

In their report, Ware et al. (2006) focused on the expansion of automatically generated schematic maps from a large dataset of digital geographic data that they were prepared for mobile GIS applications. They produced prototype software and their results showed the algorithm they applied was successful in creating schematic maps and it met the user-defined restrictions within a realistic time. For having the best results, they reported how a good set of different input parameters is required by the process of termination principles (Ware, et al., 2006).

3.4. Algorithms for Creating Schematic Maps

For creating schematic maps variety of algorithms are available. But for automated creation of schematic maps, there is a challenge in modeling between the displacement, line simplification and merging. In spite of the complexity in designing, the quality of automated method is becoming hard to make different hand drawn schematic maps from the automated ones. Schematized map of i.e. transport network displays a set of nodes and their connections in a simplified format. Since the exact shape of the connections and the place of the points is not so important, to present a recognizable map for map readers, it is important that approximate layout is kept. Therefore, different methods and algorithms are available for modeling the schematic maps to achieve the maps with the best quality (Mackaness & Reimer, 2014).

Stott, et al. (2011) developed a method to automatically draw metro maps based on ‘Hill Climbing’ algorithm. In this method, they apply several optimization criteria to find the best placement of stations with a good line layout. They starts by a preliminary state from a geographically accurate map of the location of stations and their connecting parts, then the algorithm frequently creates small displacements so as to achieve an improved solution. This algorithm is good for finding local optimums. The multi-criteria optimization which metro maps are drawn based on the hill climbing are as below (Nöllenburg & Wolff, 2011):

- For a specified layout they defined metrics information for assessing the length of edges and the number of their intersections, the angular resolution at vertices, and the straightness of metro lines.
- Then according to the sum over of the weight of these metrics parameters, they defined the quality of the layout.
- The optimization algorithm considers different grid positions for each vertex that maintain topology and improve the quality of measurement.

The Hill Climbing method in Stott, et al. (2011) is operated in this manner: at first they define a primary layout for the stations, and snap stations to the grid in a way that only one station at any point. Then, they calculate the fitness of the diagram for each station. After that, they examine the points around a rectangle which is centered on the station at a certain distance. So, they move stations to the locations with the most improve of fitness. If nothing is done, then the stations are not

moved. For all stations in the diagram, this method is performed. They also do similar manner for the layout of labels to see if they can be improved. Once position of all stations and labels has been tested, they repeat the process until no more improvement can be made. Therefore, Stott, et al. (2011) apply multi-criteria optimization approach for the hill climbing algorithms in the combination of the techniques of clustering to avoid the 'local minima' solutions which are identifying the groups of stations.

Another approach to define rules for creating schematic maps and using for solving combinatorial optimization problems is Simulated Annealing. This method, as Anand, et al. (2007) describe, starts with a preliminary state to improve accuracy and cost. If the cost is increased then this state is rejected. Simulated annealing for achieving optimal solutions, introduces a probability function P which ($P=e^{-\Delta E/t}$). The probability function P , administrates the likelihood of found solution to be accepted or rejected. This value depends on two variables: ΔE which defines difference in cost between the current state and planned new states, and t which relates to temperature (weight). Generally, t defines as a weight factor for the terms of cost reduction; it means the higher value of t and consequently the slower the rate of change then the better result could be obtained. In probability function P , t value is assigned a relatively high initial value which its value decreases by running the algorithm. At high values of t , the new states with higher cost have a relatively high chance of being preserved, while at low values of t the new states with higher cost are rejected.

For producing the schematic map, the input for simulated annealing method is initial network (line features) which is made up of edges and vertices. For evaluating the initial state a cost function is used; this function allocates a score to the input state that shows how well it matches with a set of given constraints. If the initial cost is greater than defined threshold then the algorithm steps into its optimization phase. This section can be done frequently so that in each time, the current state is customized to make a new solution, and the new states are being neighbors of the current states. The new state is chosen by selecting a random vertex in the current state and subjecting it to a small random displacement. The new state is evaluated by using cost function. According to the result of cost function, a decision is taken as whether to switch to the new state or to keep with

the current state. Always, an improved new state is chosen, while a poorer new state is rejected. The process continues until a suitably good solution is found (Anand, et al., 2007).

The procedure for doing the simulated annealing algorithm is as below (Anand, et al., 2007):

Procedure SA_SchematicMap (Initial, Annealing_Schedule, Stop_Conditions)

input: initial state, annealing schedule, stop conditions

output: Costcurrent

begin

Current←Initial

t←GetInitialTemperature(Annealing_Schedule)

Costcurrent=C(Current)

while NotMet(Stop_Conditions) **do**

 New←RandomSuccessor(Current)

 Costnew=C(New)

$\Delta E \leftarrow \text{Costcurrent} - \text{Costnew}$

if $\Delta E > 0$ **then**

 Current←New

 Costcurrent=Costnew

else

$p = e^{-\Delta E/t}$

$r = \text{Random}(0,1)$

if $(r < p)$ **then**

 Current←New

 Costcurrent=Costnew

end if

end if

 t←UpdateTemperature(t, Annealing_Schedule)

end while

end

A Force Directed Approach is another algorithm which is modeled as a set of attraction forces. One example of an attraction force is the desire for a station to be

located as close as possible to its original geographic location (Bertault, 2000). Bertault (2000) presented a frequent drawing algorithm, according to the force-directed method that keeps the properties of edge-crossing. This algorithm guarantees that two edges cross in the final drawing when these edges are crossed in original layout. Therefore, for obtaining desired layout, several criteria such as space between nodes, a standardized distribution of objects in map area, minimum crossing lines are defined.

Another example of a force direction algorithm in transportation maps is in repelling the nodes of adjacent stations to have clear division between them. The distance is used to model the efficacy of adjacent nodes, in such a way that closer nodes and vertices have greater weight than the objects that are located further away. The total force on a node or vertex is calculated by summing up all the force directions (attraction and repulsion) so that an optimal direction of movement can be found (Hong, et al., 2006).

Also, Fink, et al. (2013) used Bézier curves and by adding virtual vertices to highlight the continuity of lines by using a force directed algorithm. This algorithm has been extended to model circular arc edges to give better continuity and easier distinguish between one path to another one. In this model, edges are equally spaced around each vertex. Figure 3-3 shows the effect of virtual vertices on the schematic map of metro network of Vienna:

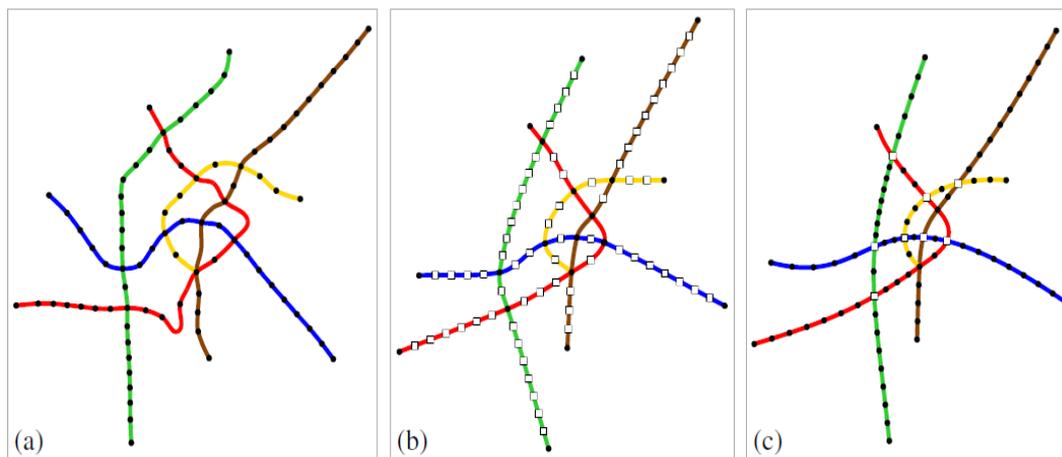


Figure 3-3: Metro network of Vienna (a) without virtual vertices, with (b) virtual vertices of degree 2 (highlighted by squares), and (c) additionally with virtual vertices of degree 4 (highlighted).

From: (Fink, et al., 2013), p. 473

One efficient algorithm for schematic map construction is presented by Cabello, et al. (2004). In their model, the input is a plan of polygonal lines between specified points (endpoints) which they represent, for example, a railroad network. The output contains a plan of all endpoints that have the same position and all lines are displayed as two or three-links lines where links are constrained to have certain orientations. Moreover, the output map must be corresponding to the input map regarding the continuous deformation in a way that no line crosses over an endpoint during the transformation. It means that the topological equivalence can be expressed in the way that the algorithm keeps the face structure in both preparations. Therefore, this equivalence causes the cyclic order of lines around the endpoints is maintained.

The method in Cabello et al. (2004) is applicable for different types of schematic maps. For example, it can be used for axis-parallel shortest paths with maximum three links, or allow links in the four main directions (axis-parallel, and angles of 45° and 135°). A minimum vertical distance between schematic lines can be specified. Details are described in the following. In this method, when the original map contains n segments, the algorithm runs in $O(n \log n)$ time.

The main workflow of Cabello et al. (2004) is as follows. They use homotopy type method to correspond the input map and the output map. Homotopy method means that two lines will be homotopic if one line can be continuously changed and deformed into another line while the start and end points of them are preserved and fixed (Efrat, et al., 2006). In addition, they try to keep the cyclic order of roads at crossings. In this algorithm, the important points for one route can be the end points of the other routes, thus it can be easily adopted to account additional important points.

For creating schematic map, Cabello et al. (2004) place each line according to the computed order from top to bottom. Therefore, each line is located at the topmost position that is probable, and the maximum freedom for other lines that need to be placed will leave. In addition in this algorithm, they can specify which type of schematic map is allowed and which vertical separation distance must be between the lines. If the order between lines is not detected in the transformed map, or the location of some schematic map is failed, then the schematic map does not exist.

For making more flexible and interactive the algorithm for the user, Cabello et al. (2004) add some editing tools in the prototype. As it is described in this algorithm, the endpoints of lines do not move, thus some adjustments are necessary to do. For example, it is useful if the endpoints of lines are merged when they are very close to each other. Because the algorithm detects some failures in cases that the lines are slightly overlapping or closer in the vertical direction than allowed (Figure 3-4, right map), the algorithm cannot schematize some lines and the original lines are kept. Also, the intersections close to the endpoints have an important role, since this forbids the ordering of the lines. Normally, this kind of problem, which is presented in inaccurate data, is resolved by editing (Figure 3-4, left map).

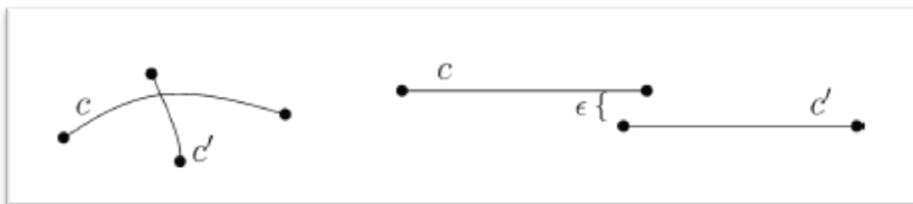


Figure 3-4: The left map shows there is not any order among lines and they intersect each other. The right map shows the minimum vertical distance between two lines cannot be estimated.
From: (Cabello, et al., 2004), p. 235

Therefore, from an aesthetic point of view, different improvements during the positioning of lines can be done. For example, one improvement is the minimum vertical distance between the schematic lines must be kept. The other improvement is lines are located in top-to-bottom and bottom-to-top order instantaneously, in the way that the bottom most lines are located in the schematic map in the possible lowest placement. So in the maps that do not have any placement order, the top-to-bottom placement order cannot be computed and the schematic map needs to be edited. This problem, as mentioned above, is because of existing inaccuracies in the topological data. Another important improvement can be done when there are two endpoints at the upper end of the lines are very close to each other. This problem causes a very close placement to another line with different endpoints in the schematic map. Therefore, editing the original map is necessary to resolve this problem. Finally, Cabello et al. (2004) concluded that in all maps, the biggest source of problems is definitely related to the endpoints that they are very close.

3.5. Advantages and Disadvantages of Schematic Maps

The advantage of using the schematic representation is observed when it is applied for the conjunction with its geographic network. The geographic network defines the information relating to the length, the distance between the points, and some other similar spatial demands. Nevertheless, when the relationships between the connections are intended to be visualized, sometimes using a geographic representation brings difficulty. In this case, an appropriate built of the schematic representation has benefits for presenting the connections in a regular environment. Using both kinds of representations (geographic and schematic) at the same time has an important step forward for understanding the relationships, both the spatial and topological, in a network. If a system is intended to provide the appropriate support for schematic diagrams, it is necessary for it to associate both schematic and geographic representation of a unit preserved in the system (Yates & Humphreys, 1998).

By having a short preview over the presented literature review and related studies, it is observed that the schematic transportation maps (in various usages) typically include little information with no detailed description of the environment of the stations or the surrounding areas. To illustrate this, people who use the public-transportation system in the city prefer to use simple maps to find their routes, the nearest stations, or the best connection to the nearest station they want to go. Yet, using the public transport and their finding routes urge them to use two type of maps: one map is used for the ordinary geographic city map to find the streets in a city, the other one is the schematic map which is used for finding the public-transportation system routes; it needs to be highlighted that the latter brings them a little bit difficulty. Although the geographic map defines the best situation for achieving the detailed information to all types of streets, a schematic map which includes the network information optimizes the readability of the structure of connections and the transportation network (Böttger, et al., 2008).

4. Schematic Mapping in ArcGIS

4.1. ArcGIS Schematics Concepts

ArcGIS Schematics is an extension to several products in the ArcGIS family, such as ArcGIS Basic, ArcGIS Editor, and ArcGIS Advanced. This extension helps the users to automatically create, visualize, edit, and control the schematic maps from a network data or from the data whose attributes contain some information about the connectivity (Esri, 2006a).

ArcGIS Schematics is a way for automating schematic representations of an ArcGIS geo-database, helping the users to better manage and visualize any linear networks such as electric powers, traffic lights, and delivery rounds. Also, by applying ArcGIS Schematics, checking the network connectivity and understanding the network architecture can be done more easily and quickly. So according to the Esri's claim in (Esri, 2014a), by using ArcGIS Schematics, it is possible to:

- Automatically generate schematic maps from a complex network.
- Control the quality of the network data.
- Optimize the designing and analyzing of the network.
- Do forecasting and planning, e.g. for modeling and simulation.
- Dynamically cooperate with the GIS through a schematic view.

4.2. Generating Schematic Diagrams

The ArcGIS Schematics extension produces schematic diagrams very quickly from the GIS data or any other data type. Three schematic components can be implemented for creating a diagram; they are schematic builder, schematic rules, and automatic layout (figure 4-1). These components can be arranged as a repeatable process for generating diagrams (Esri, 2014b).

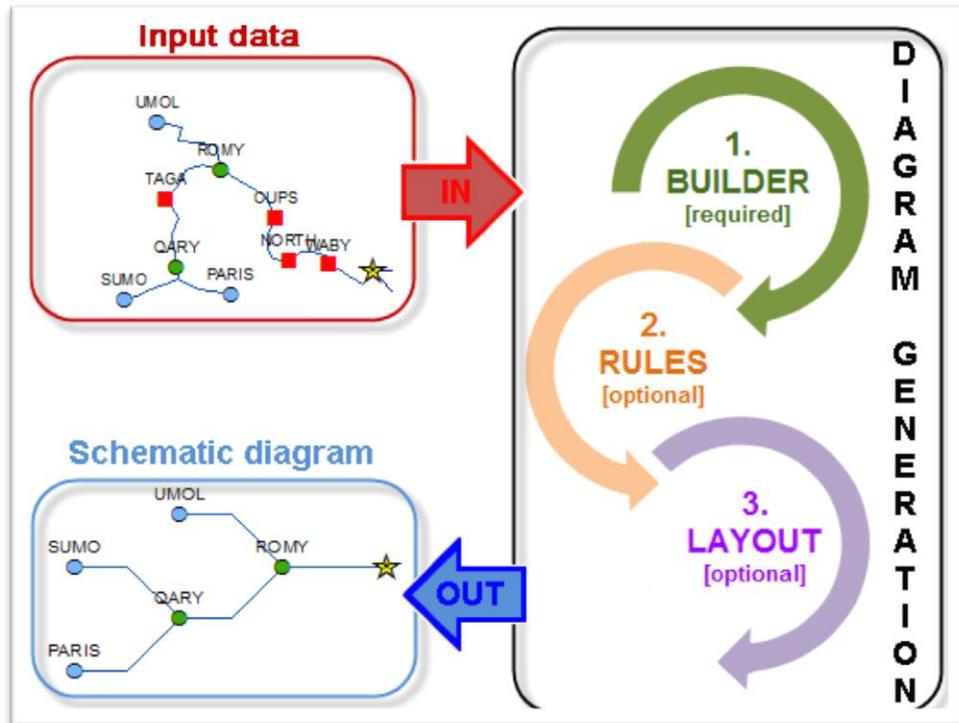


Figure 4-1: The process of generating the Schematic diagram.
From: (Esri, 2014b)

Schematic builder is the only required component for generating the schematic diagrams; yet the schematic rules and automatic layout components are optional.

- **The Builder Phase**

The first implementation in generating a schematic diagram is the action of the schematic builder. The builder is the main component in generating any kinds of schematic diagrams which needs definite input data. It can analyze and interpret this input before it transforms it into schematic features. Moreover, it works in the memory and it creates and defines a schematic feature for each element which is recognized as an input data (Esri, 2014b).

- **The Rules Phase**

The schematic rules are arranged for the type of diagrams that are generated. They perform each diagram in sequence of the current content of the in-memory diagram whose content frequently evolves rules (Esri, 2014b).

Therefore, the schematics rules are applied to the in-memory schematic features for automatically simplifying the diagram content or creating new

schematic features. These rules automatically act for the duration of generating or updating the diagram as soon as the schematic builder finishes its work on generating or updating in the memory (Esri, 2014c).

- **The Layout Phase**

Finally, the automatic layout is specified for performing and executing the in-memory diagram (Esri, 2014b). Sometimes, reading schematic diagrams are very difficult, especially when the proximity between the features is not suitable, either too close or too distant, for displaying the symbols and their explanation at the desired scale. Therefore, a set of predefined schematic layout algorithms is applied for clarifying the space between the schematic features. In addition, ArcGIS Schematics extension has a set of tools and commands for manually refining the schematic diagrams' contents (Esri, 2014d).

The most common type of layouts for creating a schematic map of transport network is *Relative Main Line Layout*. It works with information about the type of the lines in the attribute table, so that the algorithm can identify which straight lines can be as main lines and which lines can exclude from them.

4.3. Configuration Based on Geometric Network Features

One of the usages of the schematics is working on the GIS features which come from the geometric networks, such as the roads and railroads networks. These networks have critical and significant dependencies, such as stations or switches. The purpose of generating the schematic diagrams is to generate very simplified diagrams to imagine and understand the interdependencies of the network very easily and to highlight and clarify the critical and substantial elements of the network. In addition, generating the schematic map is also important as a way to make visualizations of objects related to the network appear in a good way.

A diagram template is constructed and configured to build the schematic diagrams from the geometric networks. A set of rules is defined to decrease most of the non-critical elements and thus keep the critical and important

infrastructure of the networks in the diagram. During the generation of the schematic diagram, the diagram template is also constructed to perform an automatic layout. Therefore, the residual critical elements in the diagram are set and the distance between them are normalized.

Figure 4-2 indicates how a diagram is generated based on the geometric network features' configuration. For generating such a diagram, the Schematics obtain a set of GIS features as an input. The process of generating builds a hierarchical simplified diagram that only presents the remaining critical network elements (Esri, 2014b).

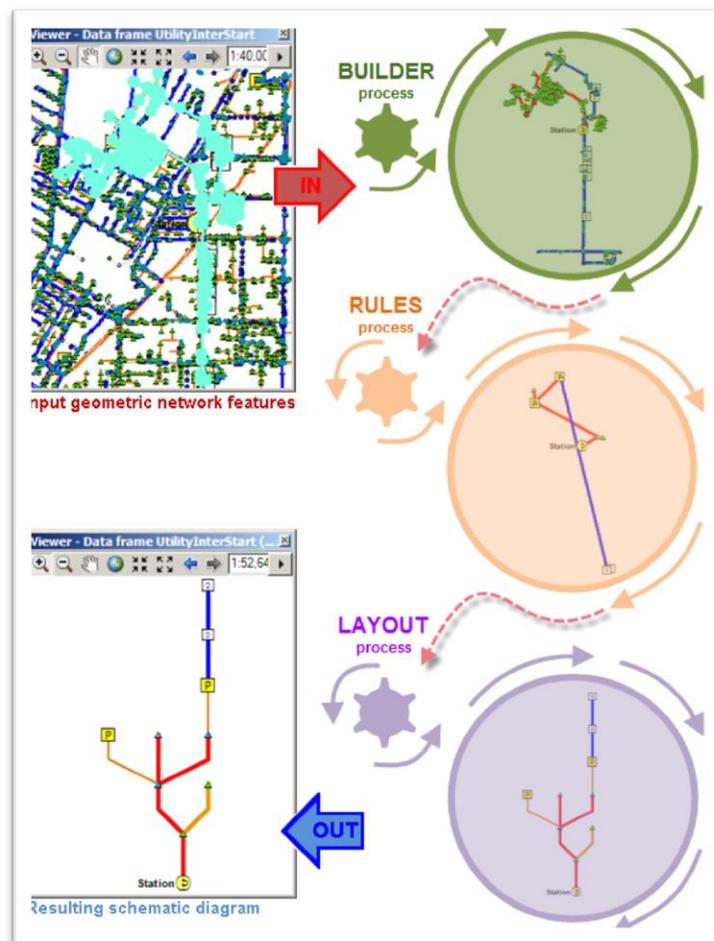


Figure 4-2: The process of generating schematic diagram based on geometric network features.
From: (Esri, 2014b)

4.4. Important Features of ArcGIS Schematics

- Automatic Diagram Generation

By ArcGIS Schematics, geo-schematic and pure-schematic views can be automatically generated from the existing network data. Using ArcGIS Schematics can help save the time and is claimed to be profitable, too (Esri, 2014a). Moreover, it is efficient in limiting the number of operations and processes and avoids the errors from manipulation and management (Esri, 2006a).

- Multi-Representation

The same set of features in a network possible to be seen by ArcGIS through a variety of graphic presentations, such as geographic, geo-schematic, and schematic presentations. It is essential to know that multiple schematics presentation, such as the logical views, yield a better understanding of organization of a network, helping to do faster decision-making (Esri, 2014a). Figure 4-3 exhibits different types of ArcGIS Schematic representations (Esri, 2006a).

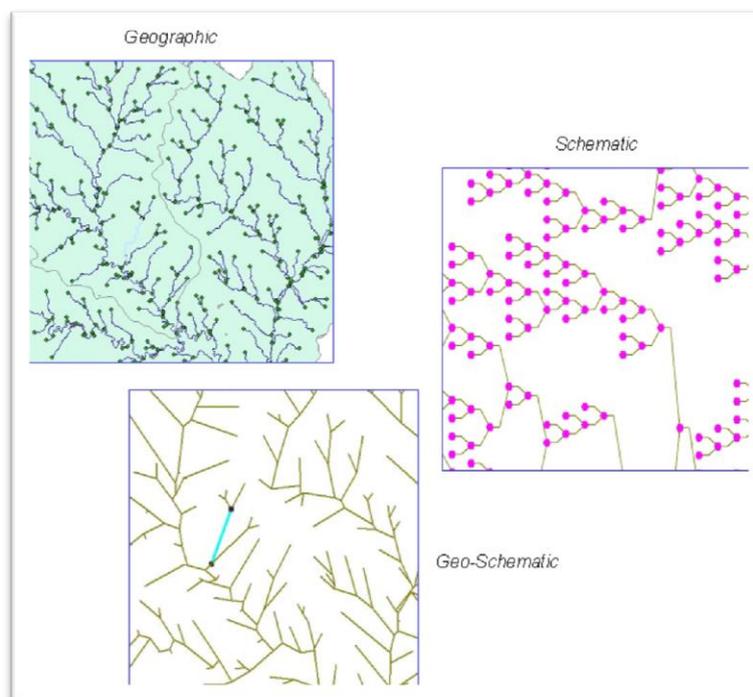


Figure 4-3: Different types of ArcGIS Schematics.
From: (Esri, 2006a), p. 7

Esri in (Esri, 2006a) asserts that the multi-presentation way gives:

- The network architecture can be displayed artificially.
- The network structure can be evaluated quickly.
- The interaction between the inside plant schematics and the equipment display can be established.
- The logical networks can be displayed.

- **The Dynamic Interaction with GIS**

ArcGIS Schematic is an extension to the ArcGIS Desktop and can work with ArcGIS Server; thus, it allows the use of versioning which helps user to repossess the information from the schematic maps to the geography maps and vice versa (Esri, 2006a).

Since ArcGIS Schematics accents on the geographic location of the features, it matches with the GIS technology in designing, constructing, and managing the networks. The diagrams can be displayed as a layer in ArcMap for simplifying the interface of the user and also for printing the diagrams (Esri, 2014a).

- **Data-Driven Solution**

ArcGIS Schematics relates directly with the features in the geo-database and it avoids duplication. Therefore, the results of ArcGIS are predictable and up-to-date (Esri, 2006a). This implies that irrespective of the data model, the symbology which is driven by the attributes and the properties in the geo-database results in preventing the differences between the schematics and the database. For easily integrating, editing, and multiple-user accessing, all information is stored and saved in a geo-database (Esri, 2014a).

- **Customizable Algorithms**

ArcGIS Schematics has layouts adjusted to several application areas. It means it is consistent with variety of demands, since different industries have diverse methods for representing their networks. They generate and use schematics for

a long time with which they are familiar, and ArcGIS Schematics offer a possible solution to this problem (Esri, 2006a). The layout algorithms of the ArcGIS Schematics represent any different types of networks or diagrams such as outside and inside plants diagrams. These algorithms are customized to fit the user's needs and the company's standards (Esri, 2014a).

4.5. Types of Representations

As it was mentioned at an earlier point, ArcGIS Schematics is applied for displaying the geographic, geo-schematic, and pure schematic diagrams. Simultaneously, the user can display different representations and views of the same set of features.

4.6. Element Types and Properties in ArcGIS Schematics

An element type (or a feature type) is defined and distinguished by a name, its class, its attributes, and properties. In ArcGIS Schematic, the elements manage two types of objects:

- nodes (junctions)
- links (edges).

A node is a vertex in a network graph and it can be presented by a symbol or by a variety of graphical attributes such as the color, the fill style, etc., or by geometric attributes such as scaling, rotation, and so forth. The nodes in ArcGIS Schematics can have geographic, geo-schematic, or graph-based coordinates. A link signifies the connectivity between two nodes in a network and it can represent different kinds of connections, such as logical connections. A link is represented by an edge in a network graph which can be represented by a direct single line segment or by several line segments which are passing through one or numerous link points. The usage of properties is for defining the characteristics of a set of objects that affect the network graphic representation. The total state of a network is defined by the values of the properties that are available at a given time (Esri, 2006a).

4.7. Dealing with Connectivity in ArcGIS Schematics

Connectivity are represented different types of information and relationships. They use for generating the diagrams that show how different objects and entities are related to each other. The most common type of connectivity in ArcGIS Schematics is physical connectivity. It is stored in the geo-database as either a network dataset or a geometric network. The ability of ArcGIS Schematics is reading networks, repossessing connectivity, and generating diagrams. A geometric network is a set of edges (lines) and junctions (nodes) which are connected together, being used for representing and modeling the conduct of a network in the real world. For example, a transportation network is defined as an undirected network, implying that although an edge defines a direction in the network, the user is free to decide its direction or speed. Nonetheless, a network dataset is created from the sources of the features available in the network. It integrates an advanced connectivity model that can represent complex situations such as multi model transportation networks (Esri, 2013).

4.8. Parameter Setting

In this project, the parameter setting was constant for different types of input data. For generating the schematic map, parameters in Relative Main Line Layout algorithm must be set. These parameters as are shown in figure 4-4 are:

- line type definition: define the attribute name that the layout algorithm wants to get the information from this
- line type attribute: define the value of main line value and the values of excluded lines
- priority attribute, define the priority for creating the schematic maps
- direction: define the direction of the schematic map, for example from left to right
- spacing: define the offset between branches, and the angle of break points
- initial distance, define the initial distance that the schematic map can get from, for example the geometry links.

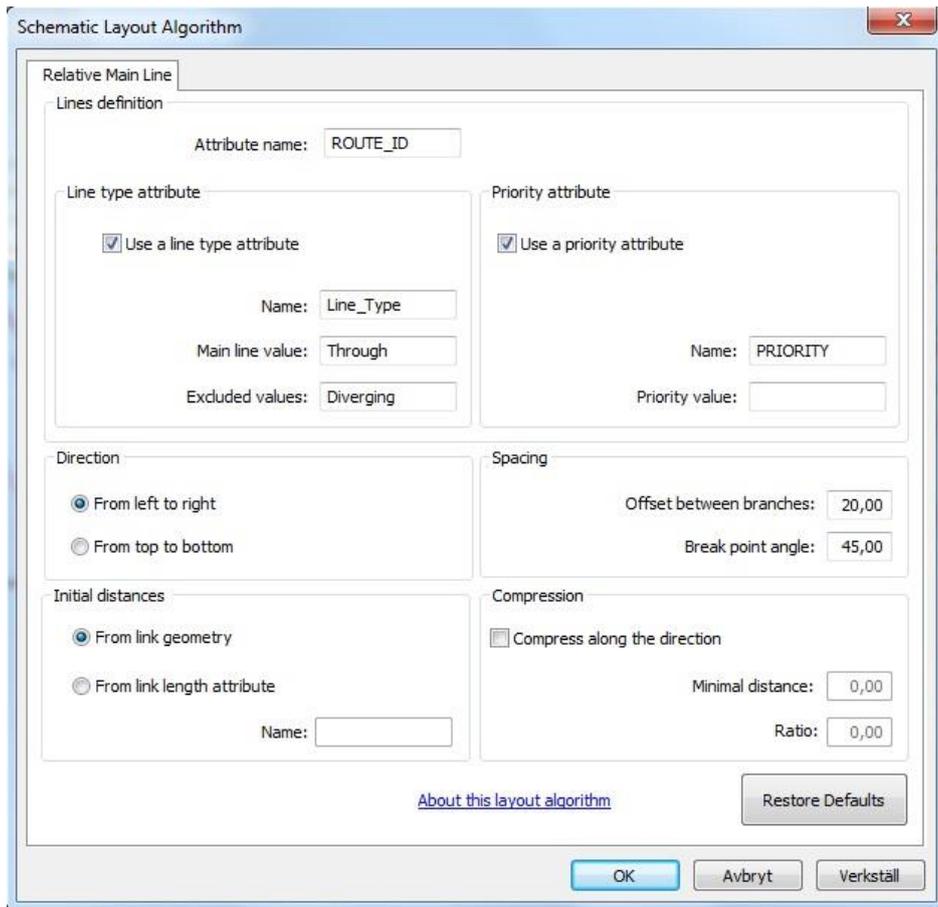


Figure 4-4: The parameter settings in the Relative Main Line Layout Algorithm.

All these settings in Relative Main Line Layout algorithm are constant, and did not change for different kinds of inputs data.

So, by just testing different kinds of input data, different results are gotten and the effect of these inputs data on the results is discussed in chapter 6.

4.9. Algorithms in ArcGIS Schematics

The algorithm used by ArcGIS Schematics extension is not published. In this section we will describe how it likely is built up.

To summarize sections 4.2, 4.3 and 4.7, the general steps for creating automatically the schematic map by applying ArcGIS Schematics extension are:

- After data are selected by (attribute, location, tracing or manual selection), a specific function reads the selected features to get object IDs.

- Then it reads the geometric network to get available connectivity in the network.
- Another function reads the selected features by Utility Network Analyst tools.
- And finally, it generates the corresponding schematic diagram.

Also, as it was mentioned in section 4.6, the important part of ArcGIS Schematics extension is the metamodel, because it needs to manage all characteristics of connectivity. The main objects in a network are nodes and links, which the links are representing the relationships between the nodes. Figure 4-5 represents how nodes, links and their connectivity can be shown within a schematic diagram.

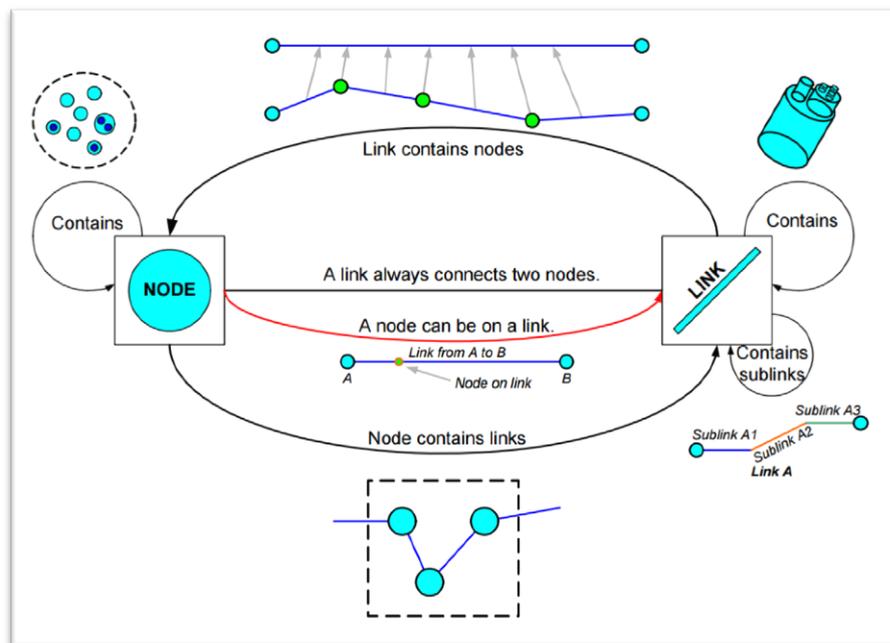


Figure 4-5: ArcGIS Schematics Network Model.
From: (Esri, 2013), p. 2

A node represents the junction in a network graph, and defines a position on a link for path route. Therefore, a node on a link is completely dependent on how different links are related to each other (Esri, 2013).

But, by reviewing different algorithms and methods for creating the schematic maps (section 3.4), it seems that the algorithm in ArcGIS Schematics extension

is similar to the algorithm in Cabello, et al. (2004). The same as their method, the input is a plan of polygonal lines between specified points and the output contains a plan of all endpoints with the same position and all lines in a two or three-links route format with certain orientations. Moreover, the output map corresponds to the input map according to the continuous deformation. It seems that the algorithm in ArcGIS Schematics uses axis-parallel shortest lines with maximum three links. It specifies a minimum vertical distance between schematic lines. It also seems that in ArcGIS Schematics, the algorithms tries to keep the corresponding and equivalent between the input map and output map by for example all paths from one map transfer to the other one by fixing the endpoints and do not across from any important point.

In Cabello, et al. (2004) method, for creating the schematic map, they place each line according to the computed order from top to bottom. Therefore, each line is located at the topmost position that is probable, and they leave the maximum freedom for the other lines that need to be placed. In addition in this algorithm, they can specify which type of schematic map is allowed and which vertical separation distance must be between the lines. If in the transformed map there is no order detected between its lines, or the location of some schematic lines fails, then the schematized map does not exist. These steps in ArcGIS Schematics extension are defined in Relative Main Line Layout algorithm. The summary of these setting, as they are described in section 4.8, are:

- Define the type of lines that the layout algorithm wants to get the information from this.
- Define the attribute type of line that which line is the main line and which line is the excluded line.
- Define the direction of the schematic map, for example from left to right or top to bottom.
- Define the space between lines and the angle of break points.

So, it seems similar parameter settings and steps in Cabello, et al. (2004) are done as in ArcGIS Schematics extension, such as defining ordering and priority number for tracks, specific distance between schematic lines and doing

some extra editing according to the aesthetic point of view in the final schematic map.

4.10. Applying ArcGIS Schematics for Services and Transportation

Commonly, in transportation administrations systems, one database stores the features of a geographic information system (GIS) while the other database or a separate set of applications keep the schematic representation of those features. However, the data which are derived in ArcGIS schematics helps the users to reference the same database as in the GIS features which are stored. Consequently, editing in the GIS application is automatically accessible as the updates are also accessible within the views of the schematic network. It means the maintenance by applying ArcGIS schematics is efficiently cut in half for administrations which have physical and logical representations for their geographic data. Thus, an ArcGIS schematics project can simultaneously connect to multiple data sources as well as the geo-database (Esri, 2006b).

For having a successful establishment of the ArcGIS Schematics, Esri suggests that following steps are required to be taken :

- Making review the data modeling, that the data from the quality issues can be corrected, such as gaps and overlapping.
- Creating the network connectivity.
- Arranging the parameters related to the ArcGIS Schematics.
- Improving the custom application algorithms.
- Finalizing the establishment.

As a result, clients and users of ArcGIS Schematics extension believe that installing it, needs special considerations to its data model, especially to the storage and maintenance of the connectivity of features (Esri, 2006b).

4.11. Other Applications of ArcGIS Schematics

It needs to be asserted that there are other experiences on using ArcGIS Schematics which have yielded interesting results. For example, Field (2009)

used schematic visualization for ski resort trails. The nature of mountain environments itself provides good traditional representation form which aesthetical and good-looking maps. Navigating on mountains is sometimes daunting because of some problems such as conditions, map perspective, and orientation. These problems make reading the map difficult. Therefore, Field (2009) improved the user's ability to navigate in the mountains.

Field (2009) captured the route data by GPS. Afterwards, he applied the data interoperability tools for importing the data into ArcGIS 9.2. ArcGIS Network Analyst tool was used for defining the topology and creating the network dataset. It could be used in ArcGIS Schematics extension for generating the geo-angled direction of schematic template in the form of horizontal, vertical, and 45° lines. In this research, Field (2009) tried to find out the challenges between the traditional trail map and a schematic map created exclusively from the route network which were formed by the lifts and trails. A trail network is a track network including lines and junctions, which is similar to the other set of interconnected linear features, such as roads or railways. These networks reduce the topological schematic diagrams to demonstrate a complete network structure. The purpose of these kinds of maps is to bring the essential and important characteristics into view by removing the context and unnecessary complexities. The method applied by Field (2009) extracts a type of a trail map by applying similar techniques for creating a schematic map.

Another application of ArcGIS schematics was in the Qatar telecommunications called the Qtel which provides services to the state of Qatar country with the population of around 2,000,000 people. The telecommunications services offered by this company include wireless and wire-line voice communications, Internet, and cable television services (Qtel, 2006). Qtel (2006) found out that over the past few years they could detect a break in their services that affected 12 square miles of the city. To this end, they needed to inspect the landline network for the most parts of the break. Seemingly, the only recourse they had was hundreds of drawing papers that showed the network area and the drawings were tied to geography; therefore, their devices were crowded and became almost unclear, especially for the areas with high density of housing. Thus, for improving the efficiency of their

operations, the Qtel automated their facilities management, such as automating their planning and engineering operations. They also used the Telcordia Network Engineer with a software-based ArcGIS to manage the data (Qtel, 2006).

Afterwards, Qtel found the applied Services appropriate in the automation of their engineering operations. Consequently, in November 2004, Qtel developed their software created on Network Engineer and ArcGIS Schematics, facilitating the network planning and its maintenance. During the project, ArcGIS Schematics were customized especially for Qtel. These customizations led to three common categories: integrating the work order system, creating some algorithms consistent with the custom layout, and recreating and automating the Qtel standardization of the marginalia of the schematic diagram.

To sum up, it was observed that applying ArcGIS Schematic helped Qtel to avoid restrictions associated with the previous processes. By this, they could save time and facilitate the customer services and their workflow (Qtel, 2006).

5. Questionnaire to other Railroad Administrations in Europe

Totally, there are three main Railroad Administrations and companies in Europe that apply ArcGIS Schematics for creating the schematic map of their railroad networks. They are ProRail in Holland, RFF in France and Network Rail in UK. For finding some ArcGIS Schematics experiences in these European railway administrations, a questionnaire was created and sent to them. Juliette van Driel from ProRail and Marchal Amaury-Xavier from RFF answered the questionnaire. But unfortunately, despite many contacts, there is not any answer gotten from the Network Rail Company in UK. Their methods for presenting their schematic representations and their usage of ArcGIS Schematics extension are asked from them (the questionnaire is available in Appendix 5). After gathering the questionnaires and obtaining their answers, their experiences are listed below:

5.1. The ProRail Company

ProRail in Holland is a national railway network infrastructure manager but it does not take care of the maintenance and extensions of the metro or tram. It allocates rail capacity and controls the traffic. ProRail is part of the Dutch railway infrastructure owner (NS Railinfratrust) which consists of the following infrastructure management organizations:

- Railinfrabeheer (Rail Infrastructure Management, RIB)
- Railned (railway capacity allocation)
- Railverkeersleiding (Traffic Control).

Also, maintaining the quality, consistency, and accessibility of the railway infrastructure, as well as allocating the capacity in a transparent way, and leading the trains are some of the obligations in ProRail for the main railway infrastructure (Russell & Cohn, 2013).

A GIS specialist at ProRail, Juliette van Driel, about their current data model explained that the switch is a part of the Rail branch, which it is not sufficient for using ArcGIS Schematics, because ArcGIS Schematics could not recognize

where the tracks break down and where the tracks excluded. Therefore, they need two switch legs as separate objects. They present the schematic representation in different forms, such as the DGN-format (the Design format, and it is the name used for the CAD format), Visio (which is an application for diagramming and preparing the vector graphics.), Paint (which is a simple graphics painting program), etc. Since these schematic networks which result from the above formats are not automatically maintained, they use ArcGIS Schematics for testing them.

ProRail used ArcGIS Schematics for a pilot to evaluate ArcGIS Schematics extension. They found some advantages associated with using ArcGIS Schematics extension:

- They can control the outcome by setting parameters like mainline-ID.
- Since the schematic is based on one maintained source, the end user can switch between the schematics and the geographical world.
- It is possible to use standard GIS functions.
- It is possible to match the schematic features with data from the other sources such as the SAP (the Structural Analysis Program).

Also, they have listed some of the shortcoming accompanying the application of ArcGIS Schematics extension:

- The outcome is not a feature class and it needs conversion to shape the format, or other suitable formats such as geo-database.
- Tunnels and fly-overs are problematic.
- The scaling in only one direction is not possible.

Finally, they believe that the performance of ArcGIS Schematics depends on many factors. Moreover, they admitted that some improvements are necessary for making it a useful application, among which directly creating a feature class so it could create a direct connection between the schematic and geographical maps. Also, improving its scale not in only one direction could help to visualize the outlook more clearly.

5.2. The RFF Company

Réseau Ferré de France (French Rail Network) (RFF) is the owner and maintainer of the French national railway network. The SNCF (the national railway company) operates with the trains but because of the European Union Directive 91/440 (Council Directive 91/440/EEC of 29 July 1991 on the development of the Community's railways) (UNECE, 2001), the French government separated the train operations from the railway infrastructure (RFF, 2009).

The missions of RFF are (RFF, 2009):

- Improving their traffic management.
- Increasing the attractiveness of the network.
- Achieving sustainable funding.
- Developing new railway lines.
- Optimizing property assets.

A GIS project manager at RFF, Marchal Amaury-Xavier, about their current experiences said that RFF only uses ArcGIS Schematics for preparing the schematic maps. For modeling the switches in their schematic representation, they have two tables: one for nodes and one for links.

In the schematic representation, they use two types of diagrams, namely the linear diagram for line representations and the global diagrams for geo-schematics representation of their whole networks. They apply the algorithm on small parts of their network and then paste small pieces together to produce the complete one. They think the Esri algorithm does not work on the complex part of their network because the complex part is non-linear, as the routes have many curves, switches, overlapping, etc. and they are not only straight lines. Even for geo-schematic representations, they prefer to produce small parts.

As it was mentioned above, RFF only uses ArcGIS Schematics for presenting their schematics map and they believe that one of its benefits is the ability to use ArcGIS Server. They can directly connect to the server and create their schematic representations easily. They also use Relative Main Line algorithm

for the layout of their railway network but they think that it is not usable as it must be.

Finally, they mentioned that one of the main problems with using ArcGIS schematics is that they need to do a lot of handmade editing in their process. In line with this, they have to separate initialization and maintenance of the diagram. For example, when they are in maintenance there will be only small modifications.

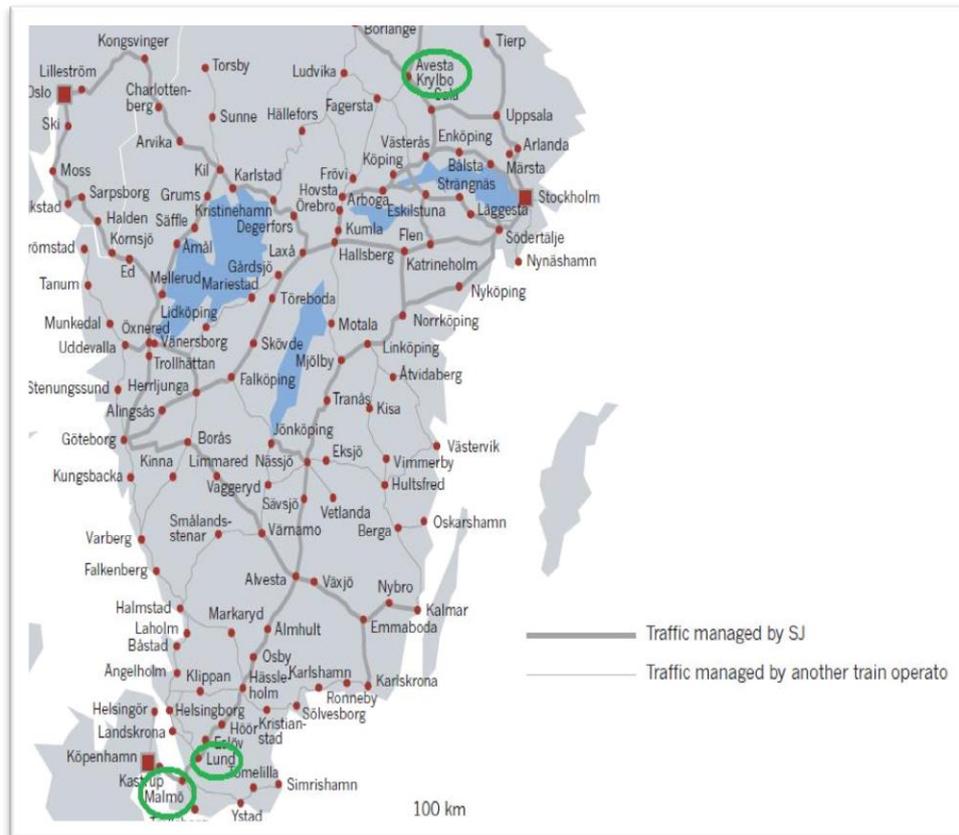
6. Case Study of Using Schematic Maps

6.1. The Study Area

At first, the study area for working on and creating the schematic map was Avesta Krylbo central station. Avesta Krylbo station located at Stationsgatan in Krylbo, about 4 kilometers from the Avesta center.

Avesta Krylbo station is a railway station in the Krylbo region in the urban area of Avesta, Dalarna County. This station was opened for the rail traffic in 1873 when the Northern Main Line between Stockholm and Storvik was opened. This station was built in conjunction with the main line between Mjölby and Krylbo, a line that helped Krylbo become one of the Sweden's most important junctions. Today, it has 4 main traveling tracks from 16 tracks. The reason for selecting Avesta Krylbo central station is although Avesta Krylbo is a small city, but its station is so complex because of its linear reference system, switches, crossing and other different assets. It has clear tracks with different types of switches and crossing.

At the end, the final result was tested for Lund and Malmö central stations. Lund central station is located on the Southern Main Line and the West Coast Line. It is bigger than Avesta Krylbo central station and has 6 main traveling tracks. Malmö is a very big central station and it also locates on the Southern Main Line. It serves around 17 million passengers per year. After Stockholm and Gothenburg central stations, it is the biggest station in Sweden. Figure 6-1 illustrates the position of these stations in Sweden.



**Figure 6-1: The position of Avesta Krylbo, Lund and Malmö central stations in Sweden.
From: The Rail Route Map, (SJ, 2014)**

6.2. Data

For obtaining the best schematic map with most equality with the schematic maps in BIS at Trafikverket and the requirements in the new information model, different geographic data are retrieved from Trafikverket and tested in ArcGIS Schematics extension. Since the main classes in the railway transport network (RailwayLinkSet, RailwayLinkSequence, RailwayLink, RailwayNode) which are respectively connected to the TransportLinkSet, TransportLinkSequence, TransportLink, TransportNode elements of the transport network package, and especially all of them are associated according to the RefLinkPart data, so we just use this kind of data but in different conditions as below:

- 1- *RefLinkPart* data which have the information about the tracks.
- 2- The reclassified *RefLinkPart* data which reclassified into three different types of tracks namely the *Normal Huvudspår*, *Avvikande Huvudspår* and *Sidospår*. The explanation of *RefLinkPart* data and its different track types, and also all other feature classes which are introduced in the following are available in the abbreviation list at the beginning of the report.
- 3- The reclassified *RefLinkPart* data from the previous step and the *SpårVäxel* feature class which has information about the switches.
- 4- The *Spårnummer* feature class which has information about the tracks number and the *SpårVäxel* feature class.

6.3. Methodology

1- The RelinkPart Data

At the beginning, the original data of Trafikverket, the *RefLinkPart* data, for creating the schematic map were used. *RefLinkPart* data is a linear transport network element which is used for providing a connection between the features and elements and has the information about the tracks. Therefore, the links and nodes are described by the classes of *Transport-Link* and *Transport-Node*. The nodes describe the places where it is probable to create route choices in a network, such as the junctions or in the switches. Furthermore, they describe locations where the network ends. For describing the manner of traveling between the nodes in the network, the links are defined, each line connects two nodes (Informationsmodeller, 2013). An illustration of *RefLinkPart* data is depicted in figure 6-2:



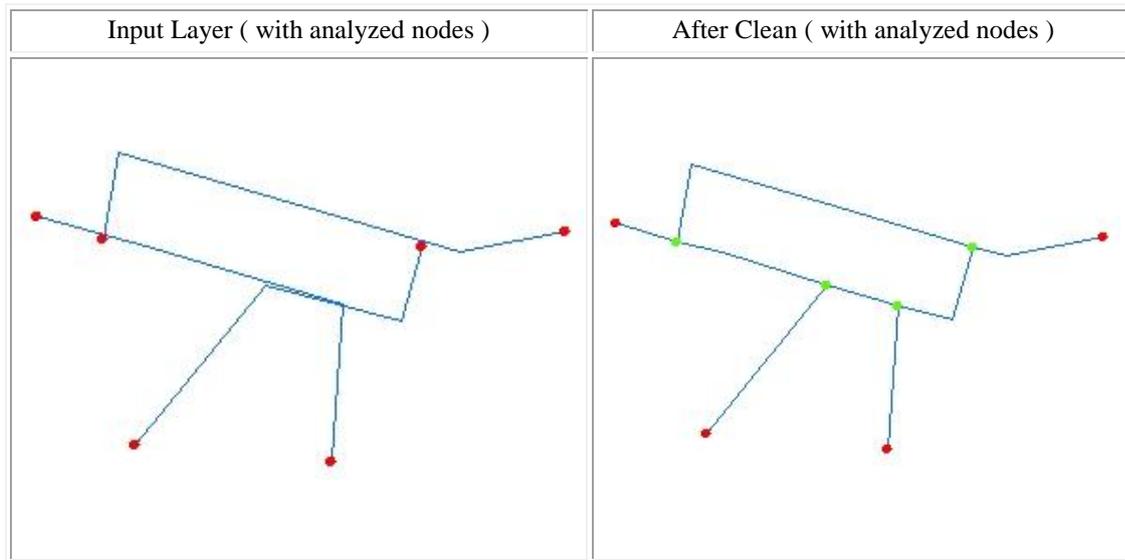
Figure 6-2: Example of RefLinkPart data.
From: (Informationsmodeller, 2013), p. 31

As it was mentioned above, the input data for creating the schematic map in this project was the RefLinkPart data of the railway network of Sweden. For creating the schematic map, the data must be organized into a Network Dataset or a Geometric Network. In these cases, the Schematics can be constructed to decode the topology of the network and transform this network data to the schematic nodes and schematic connected links.

To ensure the topological correctness of a polyline feature data set in the network, a clean polyline wizard called *ETCleaned Layer command* (Tchoukanski, 2013) was used to clean the RefLinkPart polyline data. The input data for Clean Polyline Wizard was a polyline feature layer (RefLinkPart layer) and the output was a new topological correct Polyline feature class (CleanRefLinkPart layer). The results obtained by applying this function are in brief:

- The nodes are created in all intersection points.
- The redundant data are eliminated.
- Each set of duplicate lines is replaced by a single polyline which carries the attributes of one of the original polylines.
- The attributes of the input data set are preserved.

An example of the Clean Polyline Wizard is provided in figure 6-3:



**Figure 6-3: Example of Input Layer before and after implimenting Clean Polyline Wizard.
From: (Tchoukanski, 2013)**

2- RefLinkPart data reclassified into different track types

One of the specifications of the RefLinkPart data is defining the type of the tracks. One track can be a main track in the route called Normalhuvud spår, a deviant track called Avvikande huvudspår, or a siding called Sidospår. Therefore, in the second stage, the RefLinkPart data was reclassified into these different types of tracks, namely Normalhuvud spår (red color), Avvikande huvudspår (blue color), and Sidospår (green color) (figure 6-4).

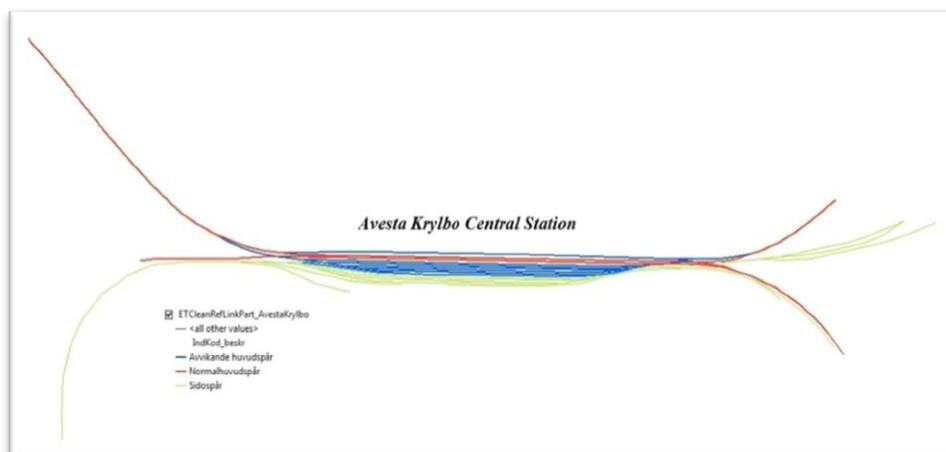


Figure 6-4: The geographic view of the Avesta Krylbo central station with identifying different types of tracks.

3- Reclassified RefLinkPart data and Spårväxel Feature Class

In the next stage, the RefLinkPart data which was reclassified in the previous stage and Spårväxel (Switches) feature class are used together for creating the geometric network. Before creating the geometric network, the location of switches was erased from the RefLinkPart data. This work can be done since the switches are linear objects and they can be removed or erased from the RefLinkPart data. In this step, I wanted to have two separate feature classes; one just for the switches and one for the tracks where the location of switches between the tracks is empty (figure 6-5).

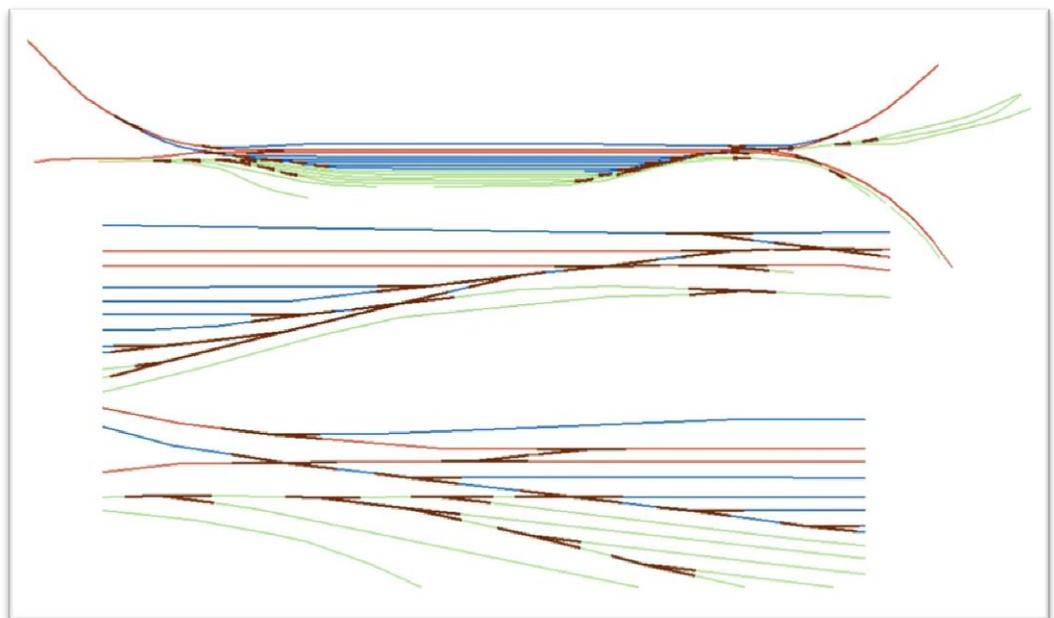


Figure 6-5: The geographic view of the Avesta Krylbo central station with assuming different types of tracks and switches.

Another test that was done is on changing the shape of the switches. Since the switches had 3 legs, I removed one of the legs which are located along another one and test the result with 2 legs switches. The purpose was to see the effect of the shape of the switches and the number of their legs on the schematic view (figure 6-6).

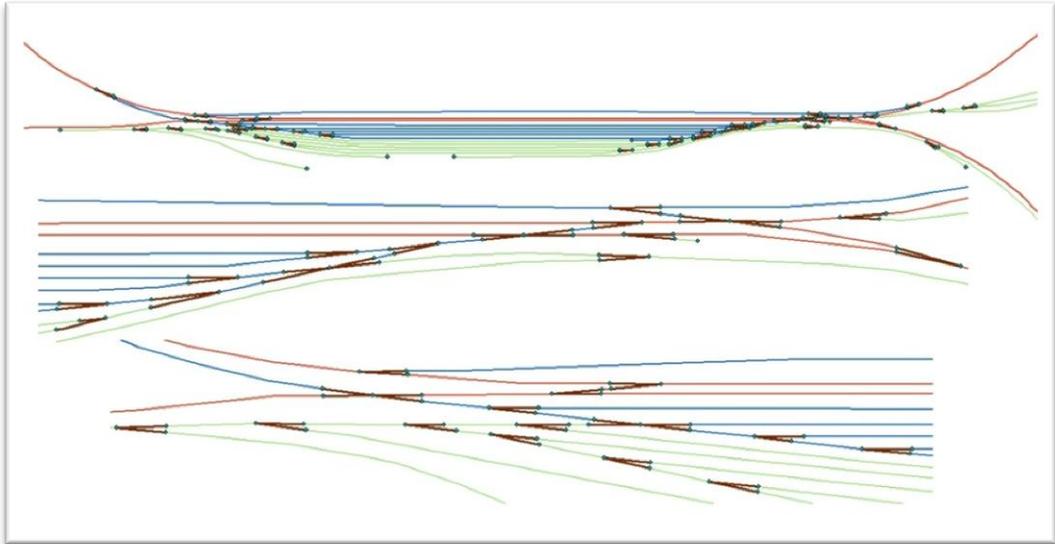


Figure 6-6: The geographic view of the Avesta Krylbo central station with assuming different types of tracks and switches with two legs.

The final test in this stage was adding a new feature type called `LINE_TYPE` which its value was 0 and 1. `LINE_TYPE` (0) was for the Avvikande Huvudspår and Sidospår, as well as `LINE_TYPE` (1) for the Normal Huvudspår. The switch legs also received values equal to the values of the tracks that are connected to them (figure 6-7).

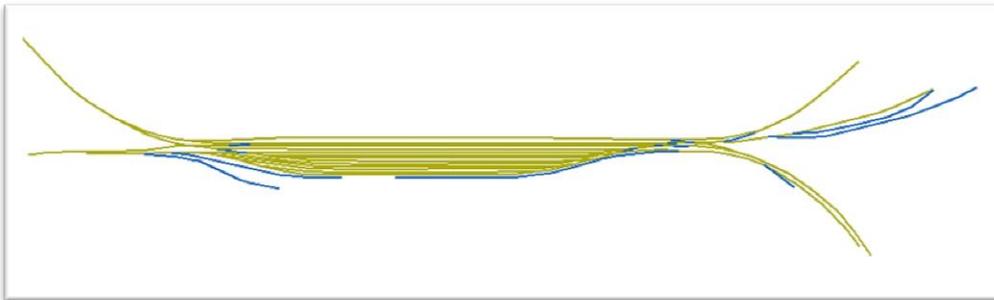


Figure 6-7: The geographic view of the Avesta Krylbo central station with assuming new attribute (`LINE_TYPE` 0 & 1).

4- Spårnummer and Spårväxel Feature Classes

In the last stage, the `Spårnummer` feature class which included the number of the tracks and the `Spårväxel` feature class which encompassed the switches information were used together. The reason for using `Spårnummer` data is that it

has the information about the number of the tracks, and it helped me to define the type of the lines. However, the structure of this data and the RefLinkPart data was the same, and if the RefLinkPart data had the information about the number of tracks, thus they could be used.

In this case, the location of switches from the tracks was also erased. Consequently, two separate feature classes were available: one just for the switches and one for the tracks.

At the end, the new feature type to the attribute table of the tracks and the switches feature classes was added. The track and legs of the switches that were located along each other and acted as a main line were defined as *Through* value, and the ones that acted as excluded tracks or switches were specified as *Diverging* value. The meaning of the *Through* and *Diverging* values as is shown in figure 6-8 is that the *Through* lines and switch legs are the main routes and almost they are straight lines. The *Diverging* lines and switch legs connect the main lines or they are the ways that help drivers change their routes, therefore, they exclude from the main lines or switch legs.

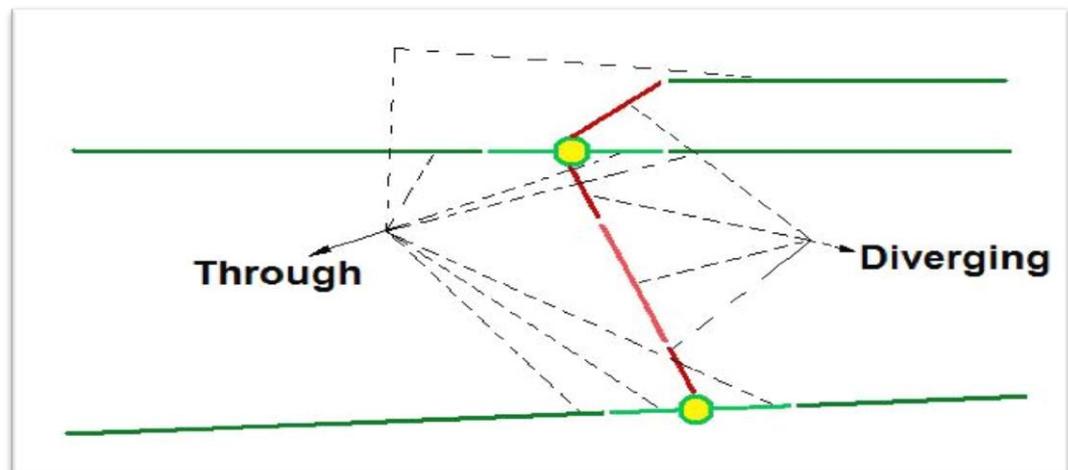


Figure 6-8: The illustration of the Through and Diverging tracks and switch legs.

As summarize, the steps for creating the schematic map in ArcGIS Schematics extension are:

- Add the RefLinkPart data and Spårväxel feature class to the software.
- Clean up the place of the switches from the RefLinkPart data.
- Add the new feature type to the RefLinkPart data and Spårväxel feature class.

In ArcCatalog Tab:

- Create a File Geodataset for the central station, and add the RefLinkPart data and Spårväxel feature class.
- Create a geometric network from RefLinkPart data and Spårväxel feature class.
- Create the Schematic Dataset on the Geodataset.
- Run the Schematic Dataset Edit toolbar, and then:
 - o Add the New Schematic Diagram Template, and
 - o Import the feature classes and the geometric network from the intended .mxd file,

In ArcMap:

- Select the features in the .mxd file for which it is intended to create schematic maps, and
- Start *Generating New Schematic Diagram*.

The diagram generation was started and the result of the schematic diagram was displayed. A detailed description of how a schematic map generate in ArcCatalog tab and in ArcMap is given in Appendix 6.

7. Result of Case Study

7.1. The Output Results

In this section the result of the case study performed as in section 6.3 is reported. The section intends to illustrate the effects of different kinds of input data on the shape of the schematic map. Data in Avesta Krylbo central station were tested and then the final result for Lund and Malmö central stations was investigated.

The current schematic map of Avesta Krylbo central station which is created manually in BIS at Trafikverket is given in figure 7-1. Since the BIS users fulfill the current requirements on a schematic map, the schematic map in BIS is used as a model for me and I tried to get a similar shape to this.

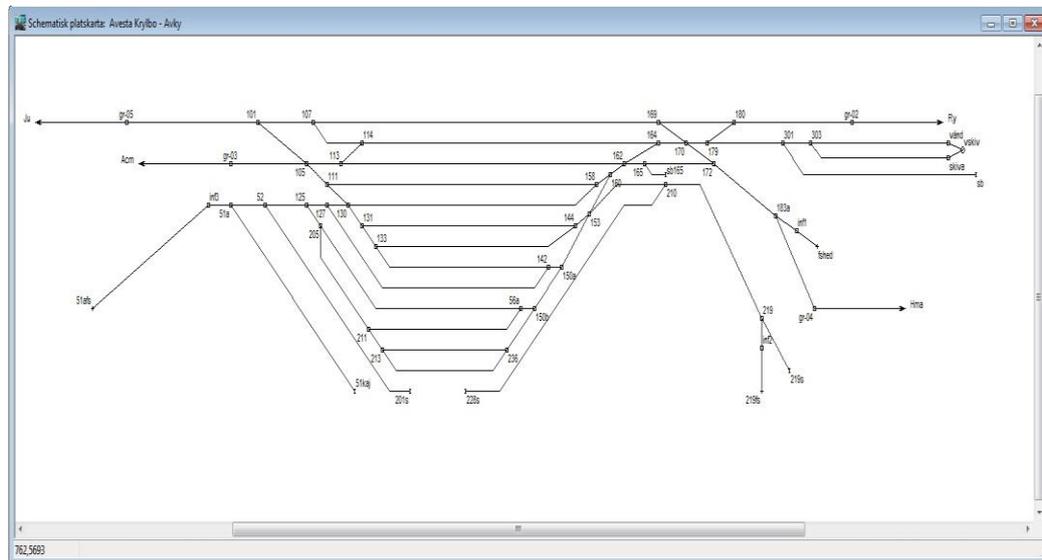


Figure 7-1: The Current Schematic view of the Avesta Krylbo central station at Trafikverket.

As it was mentioned in section 2.4, for creating the schematic maps in BIS, there are not specific rules. But it can be estimated that the break point angles are 45° , or the space between lines is about 100 pixels. In addition, a line can have several break points and bends.

Also, as it was mentioned in section 4.8, the parameter setting in ArcGIS Schematics extension was constant for different types of input data. For generating the schematic map, the parameters in Relative Main Line Layout

algorithm must be set. The main parameters are line type definition, spacing and angel of break points. The spacing equal 20 meters and break point angel equal to 45° were constant for all steps, but the values that are used in each step for line type definition were different.

So, by just testing different kinds of input data as described in section 6.3, different results were obtained. These input data and their results are:

Stage 1:

By using only RefLinkPart data in this stage, and not specifying any line type definition, the result shows that there are some loops in the data (although they were cleaned up by Clean Polyline Wizard). Therefore, as it is shown in figure 7-2, there are some sharp pick points in the schematic map, especially in the crossings.

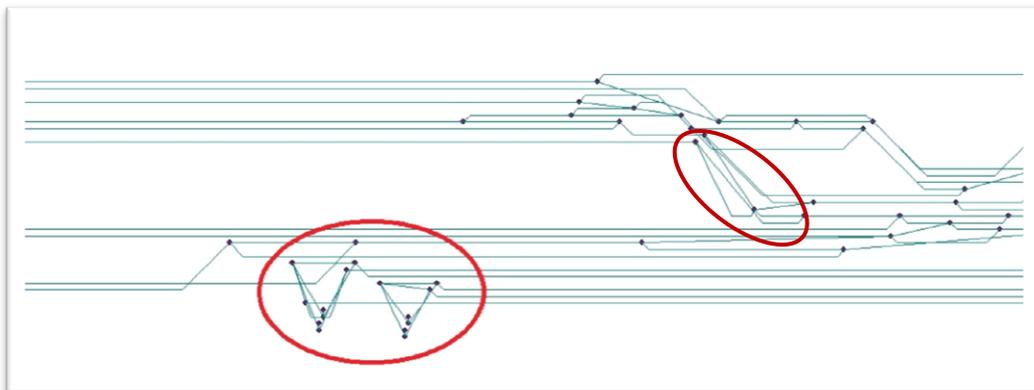


Figure 7-2: The schematic view by applying only the RefLinkPart data.

In addition, the crossings are created in wrong shape and position, and they bear no similarities with the reality or with the geographic map. Figure 7-3 shows the reality crossings which are revealed in the wrong shape in the schematic view in figure 7-2.

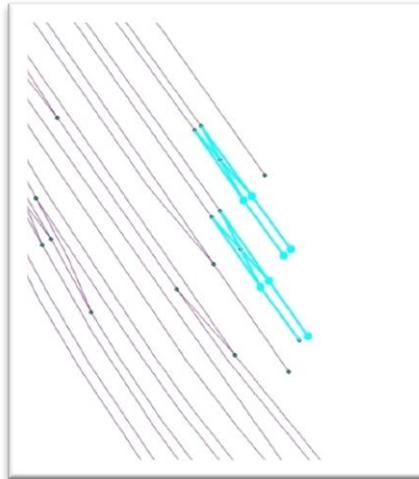


Figure 7-3: The geographic view of some crossings in reality.

Stage 2:

In the second stage, by reclassifying RefLinkPart data into three different types of tracks, the result of schematic map does not have sharp pick points as in stage 1 (figure 7-4). The line type definition settings in Relative Main Line Layout algorithm are the same as below:

- Normalhuvud spår (red color) was as the Main line value
- Avvikande huvudspår (blue color) and Sidospår (green color) were excluded.

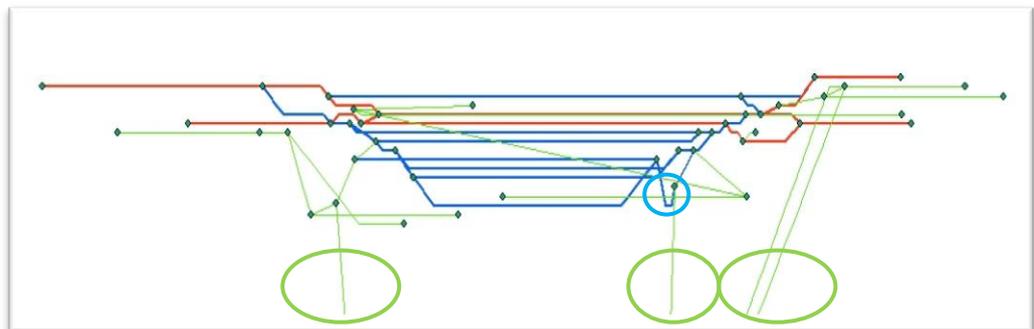


Figure 7-4: The Schematic view of Avesta Krylbo central station with specification of different track classes.

The map in figure 7-4 shows there are some loops in the data (blue circle). The Sidospår do not create truly and they are stretched to the wrong directions (green circles). In addition, crossings are not created at all.

Stage 3:

In the third stage, by applying the switches feature class along with the RefLinkPart data, the result shows that the schematic map, in comparison with the result in stage 2, still has problem, especially at crossings and switches (figure 7-5). The line type definition settings in the Relative Main Line Layout algorithm were the same as below:

- Normalhuvud spår (red color) was as the Main line value
- Avvikande huvudspår (blue color), Sidospår (green color) and Spårväxel (brown color) were excluded.

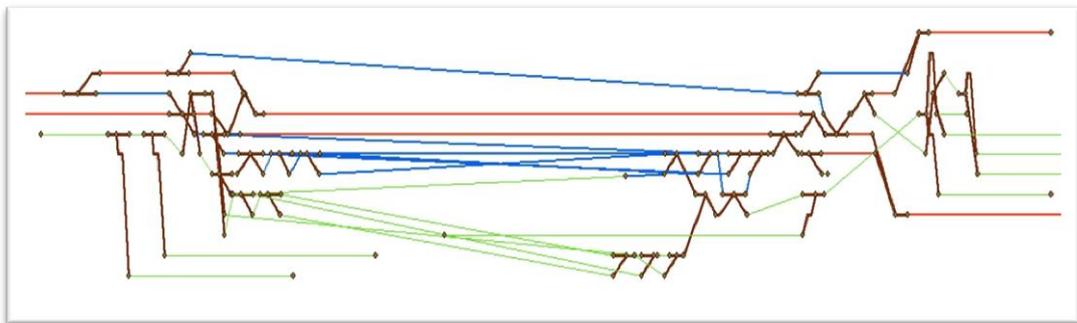


Figure 7-5: The Schematic view of the Avesta Krylbo central station with assuming different types of tracks and switches.

The switch legs do not have any specification or information regarding their type and their role in the route. Therefore, they cannot locate truly in the route and connect to the tracks in a logical way.

By removing one of the legs of the switches which are located along another one, the result shows that decreasing the number of the switch legs and changing their shapes does not have any specific effects on the result of the schematic map. The final result in figure 7-6 does not have any evident difference with figure 7-5.

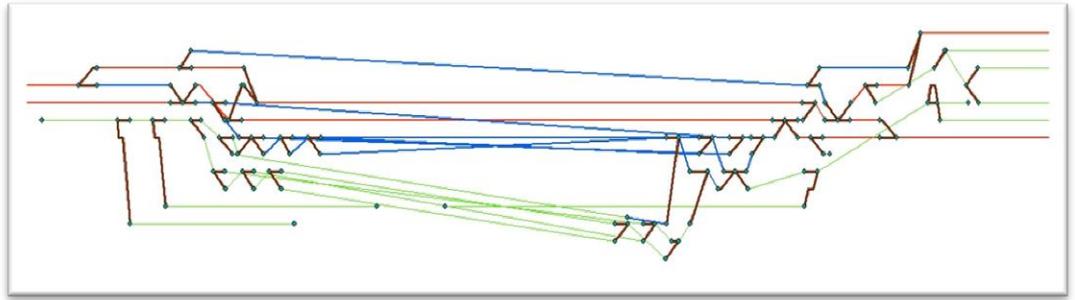


Figure 7-6: The schematic view of the Avesta Krylbo central station with assuming different types of tracks and switches with two legs.

Finally, by adding the new feature type (LINE_TYPE) to the attribute of feature classes, the obtained result was really more similar to the Trafikverket's schematic map (figure 7-7). The tracks are created straightly, and most of the switches are connected to the tracks truly. But still, some of the switch legs and tracks (such as in red circle) do not have their true position, and therefore they are generated in wrong way.

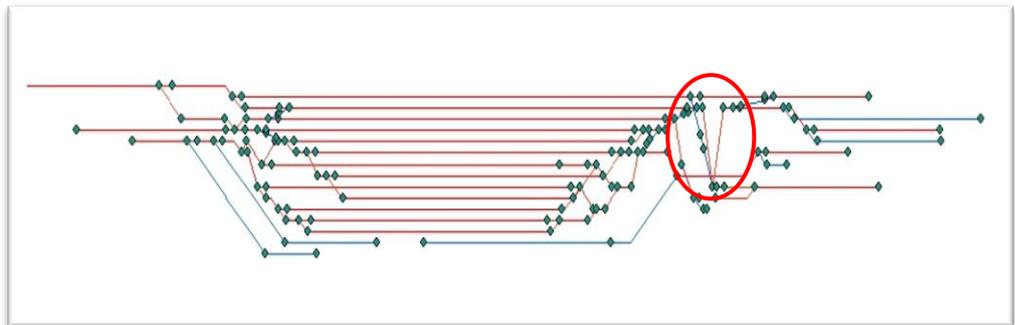


Figure 7-7: The schematic view of the Avesta Krylbo central station with assuming new feature type (LINE_TYPE 0 & 1).

Stage 4:

With more accuracy on the position and the roles of tracks in the route, and using the new definition of line types as *Through* and *Diverging* for tracks and switch legs, the original output of ArcGIS Schematics extension for Avesta Krylbo central station has more similarity to the Trafikverket's schematic map (figure 7-8). All the tracks and switch legs are located in their true position,

except the three marked tracks. Respectively, the switch legs which are connected to these tracks are created wrongly. The tracks must be moved down to locate in true position. Therefore, the correspondence connected switch legs will locate truly. These manual editing are explained in section 7.2.

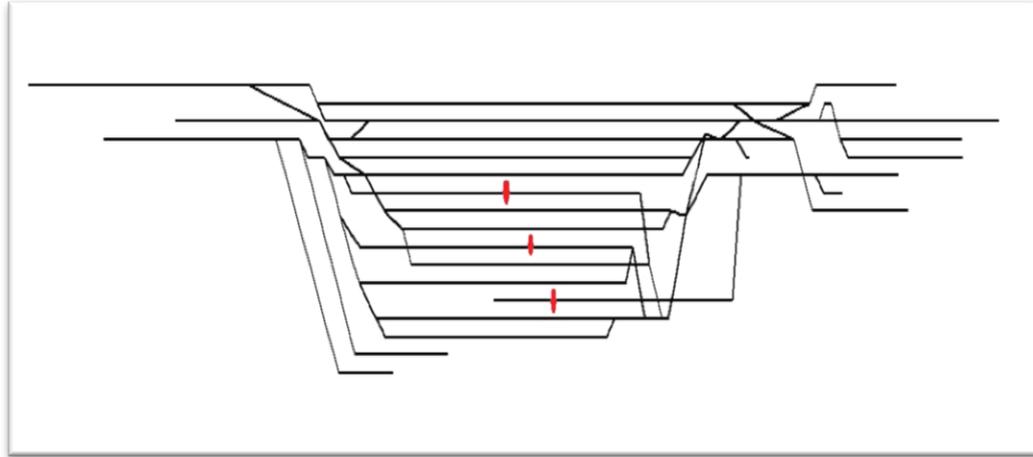


Figure 7-8: The schematic view of the Avesta Krylbo central station with creating the new feature type definition (LINE_TYPE Diverging & Through).

7.2. Manual Editing

Since the automatically generated schematic map still is not completely the same as the Trafikverket's schematic map, it needs some small manual editing. The main problem in the schematic map of Avesta Krylbo central station was in the parts that several switches connect to each other without any tracks between them. Therefore ArcGIS Schematics could not locate the three marked tracks in figure 7-8 in their true location. These tracks were connected to the other legs of these switches and therefore they moved up. These main three tracks must move down and locate in their logical places. In addition, by doing some optional manual editing such as moving or rotating other tracks, regarding the aesthetic view, the exact view as the Trafikverket's schematic map in BIS was obtained (figure 7-9).

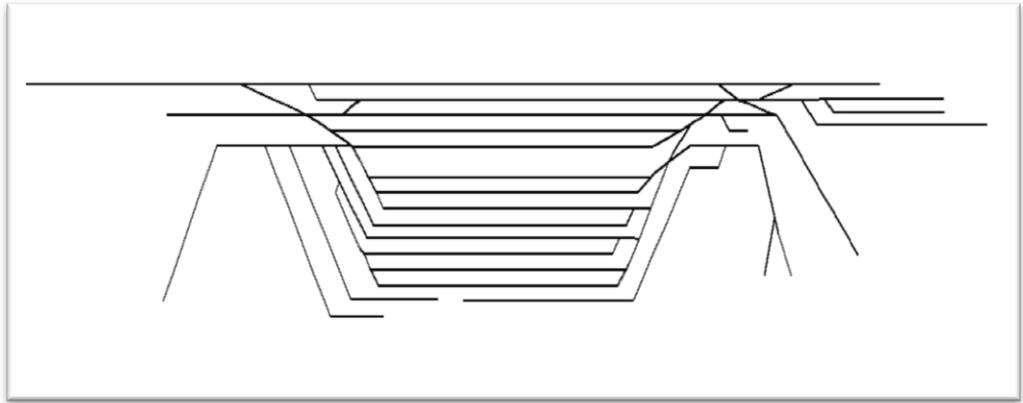


Figure 7-9: The schematic view of the Avesta Krylbo central station after some manual editing.

7.3. The Schematic Maps for Lund and Malmö Central Stations

At the end, ArcGIS Schematics extension was tested for two other stations: Lund and Malmö central stations. As mentioned in section 6-1, Lund central station is bigger than Avesta Krylbo central station and has more tracks. Avesta Krylbo central station has 4 main tracks and Lund has 6 main tracks. And Malmö central station is a sample for a very big central station in Sweden with a lot of tracks and much more complex railway assets.

The schematic map for Lund central station which is created by BIS in Trafikverket is shown in figure 7-10, and the original output of schematic map from ArcGIS Schematic is shown in 7-11.

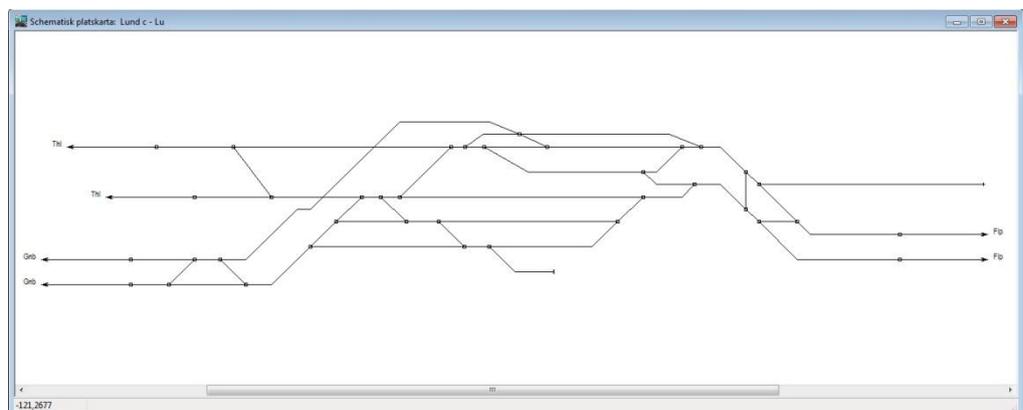


Figure 7-10: The schematic view of the Lund central station in BIS.

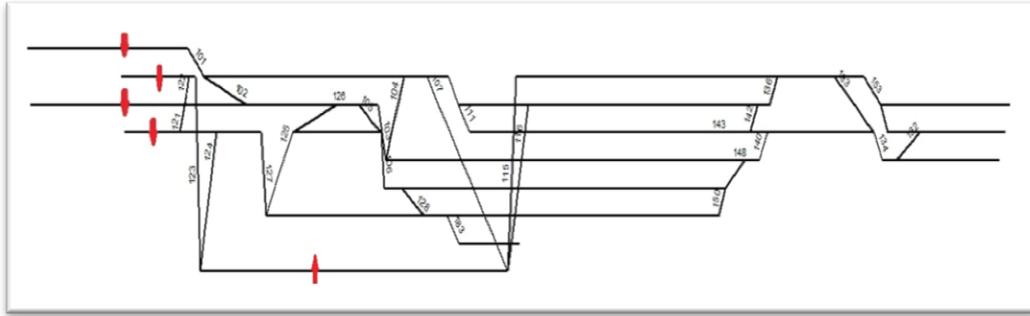


Figure 7-11: The original output of schematic map of the Lund central station from the ArcGIS Schematics.

The original output of Lund schematic map shows that one of the main tracks in figure 7-11 (the lowest marked track) which across over some other tracks and also four other upper marked tracks do not locate in their true location and respectively, they need to move up and down. Therefore, by editing and moving these marked tracks and locating them in their true position, the exact view of schematic map as the schematic map in BIS in Trafikverket was obtained (figure 7-12).

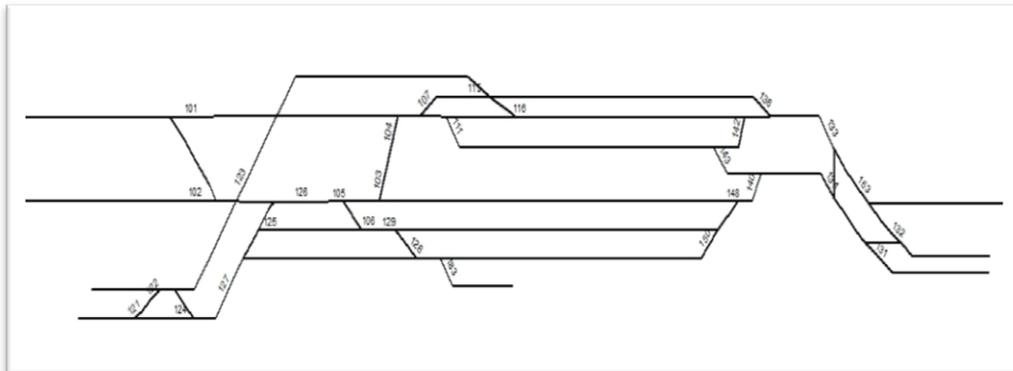


Figure 7-12: The schematic view of the Lund central station after some manual editing.

The schematic map for Malmö central station in BIS is shown in figure 7-13, and the original output of the schematic map from ArcGIS Schematics is shown in figure 7-14.

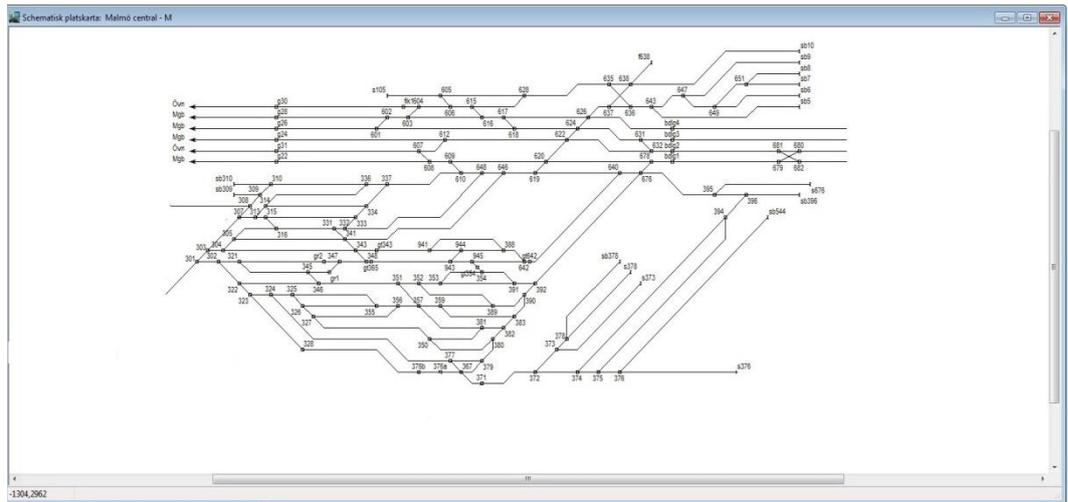


Figure 7-13: The schematic view of the Malmö central station in BIS.

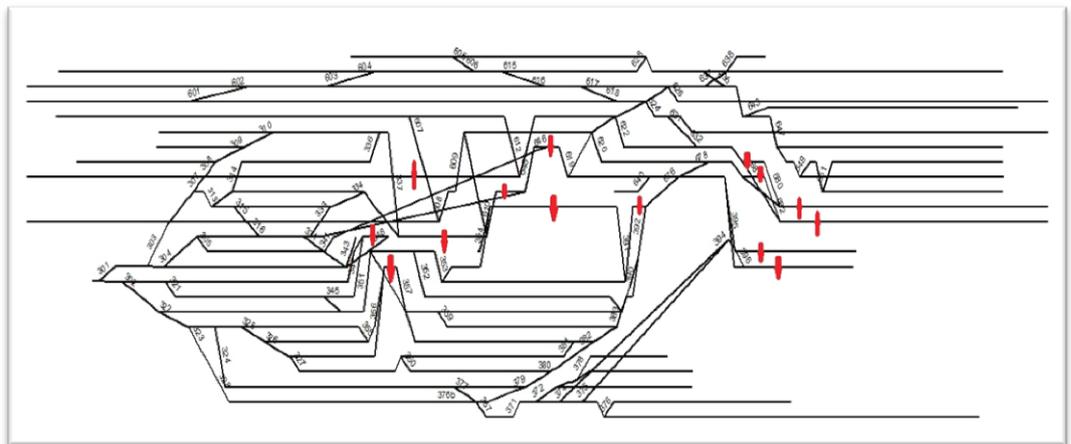


Figure 7-14: The original output of schematic map of the Malmö central station from ArcGIS Schematics.

Malmö central station is formed from two different routes: one in the North and one in the South, which they are connected to each other by some central diagonal tracks. The result of the original schematic map shows that there is some problem in generating connections between these two routes. In figure 7-14, around 15 tracks are marked which they are connected to these central connection tracks. These marked tracks do not locate in their true location. By moving these connected lines and locating them manually in their true position, also by moving or rotating optionally some other tracks, regarding the aesthetic view, the schematic map was the same as the schematic map in BIS (figure 7-15).

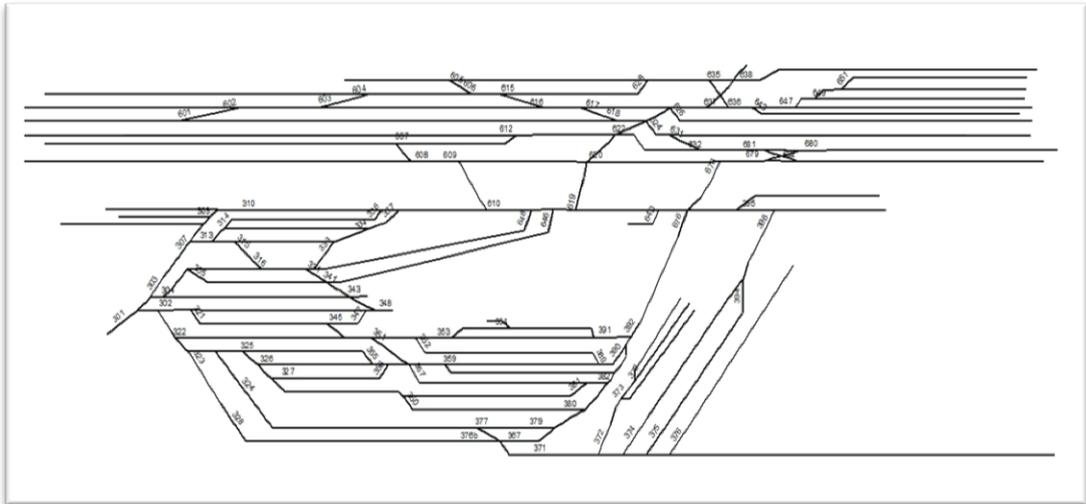


Figure 7-15: The schematic view of the Malmö central station after some manual editing.

In all these stations, the time for manual editing and also for updating the schematic map is obviously less than the time for manual creating and updating the schematic map in BIS. The maximum time for creating and updating the schematic map in ArcGIS schematics extension e.g. for Lund central station is around one hour, while in BIS, it consumes at least 3 days. Therefore, these small manual editions are completely acceptable for Trafikverket.

7.4. Comparison the Manually and Automatically Generated Schematic Map

Trafikverket currently uses BIS for creating the schematic map. The users at Trafikverket get some drawing from consultancies, and then they draw it manually in BIS. According to the position and the shape of the station, they decide how it should look like. The New Information Model Traffic Network - Road and Railway uses the same data as in BIS. In both model (BIS and the New Information Model Traffic Network - Road and Railway), they use RefLinkPart data. Using this type of data for creating the schematic map by ArcGIS Schematics extension could be acceptable if Trafikverket just add the new feature type (Line_Type) to them. In addition, they have to improve the quality and accuracy of their data.

7.5. Evaluating the Information Model Provided by Trafikverket

There are more advantages than disadvantages to using ArcGIS Schematics over BIS for creating maps. The following list summarizes these pros and cons based on the most important criteria.

- *Manual work:* The view and the shape of the schematic map in BIS is completely personalized. According to the position and the shape of the station, the responsible person decides how the schematic map must look like. The person manually creates the schematic map in BIS, while in ArcGIS Schematics the software automatically generates the schematic map. Therefore, with the latter method, the individual's ideas do not have any specific role in generation, except in some final manual editing.

- *Errors:* To generate a schematic map in ArcGIS Schematics and reduce the errors in the schematic map there are some specific rules, such as:

- Use line type attribute and define the main line value and the excluded values.

- Define the break point angle and the space between lines.

This is an advantage over BIS, where there are no equivalent rules and the final product relies more on the user's individual ideas and choices, increasing the likelihood that errors will occur.

- *The level of generalization:* The high level of generalization and standard parameter setting in ArcGIS Schematics make the software valid for all kinds of stations. While the ArcGIS Schematics software is valid for all kinds of stations, the usability of BIS is more limited and the set-up is completely different from one station to the next.

- *Time for creating one schematic map:* The ArcGIS Schematics extension brings great time savings over BIS. For example, it takes around one hour to automatically create or update the schematic map of Lund central station, for example, and of Malmö central station between one and one and half hours. The same maps in BIS would take two to

three days: at least one to draw the schematic map, another day to update the database, and perhaps one more to draw the geographic map.

- *Aesthetics*: The schematic maps in BIS are generally more aesthetics than the schematic map in ArcGIS. The schematic map in BIS is completely personalized and the users draw it in the way that it looks nice and completely clear and intelligible. In ArcGIS Schematics map, some lines do not locate in their true locations and they need to be edited, such as the connected lines between two different routes in Malmö central station or in some places which several switches connect to each other without any tracks between them in Avesta Krylbo central station. Therefore, in these places the shapes are not so nice and clear and they need some manual editing.

The criteria for defining the visual aesthetics of a schematic map is nice or bad can be as below:

- The lines should not intersect each other.
- There would be enough space between lines.
- A certain angle would be allowed for breaking down the lines.

These criteria are fully met in both models of all stations except for Malmö central station: the first criterion does not meet in ArcGIS Schematics. In some places that ArcGIS Schematics has problem for truly generation the schematic map, such as in connection lines between two different routes in this station, these connected lines across over other lines and intersect them. This event undermined the aesthetics of the schematic map in ArcGIS Schematics. Since the users in BIS draw the schematic map manually and break the lines in different distances, the schematic map in BIS is nicer and clearer.

The comparison between the creation of schematic maps in BIS and the generation of schematic maps through the ArcGIS Schematics extension is summarized in Table 7-1.

Criteria	Manual work in BIS	Automatic work in ArcGIS Schematics
Manual work	Extensive	Little
Errors	High	Low
Level of generalization	Low	Very high
Time for creating one schematic map	More than two days (for example for Lund central station)	Less than one hour (for example for Lund central station)
Aesthetic	Very good	Good

Table 7-1-: The comparison between the creation of the schematic map in BIS in Trafikverket and the generation of the schematic map through the ArcGIS Schematics extension.

8. Discussion

In this study, two types of problems have been observed in the data model; one relates to the suitable information in the input data, i.e. defining the exact role of the tracks and switch legs in the route, and the second relates to the topology of the routes, i.e. how the tracks and switches are connected to each other.

The first problem requires improvement of the information model at Trafikverket, such as the role of the tracks and switch legs in the network. The “Line_Type” feature type needed to be added to the attribute table of Trafikverket data, to the RefLinkPart data or the Spårnummer data and also to the Spårväxel feature class. This new feature type has to define which track and which switch leg has a *Through* role in the route and which of them has a *Diverging* role. It must be clear for the software which line-type is the main line and the others extract from them. Not all the tracks and switches have the same level in the route; some of them are the main line whereas some of them are subsets being extracted from the main lines. In addition, for creating the schematic map, the Spårnummer or RefLinkPart data could not be used alone, as they only have information about the tracks. The Spårväxel feature class was needed in order to have the information about the switches and their roles in the route. Accordingly, by using both information about the tracks and switches, the geometric network can be created, and then the schematic map, by using the ArcGIS Schematics extension, can be generated.

The second type of problem in this study was related to the shape of the connections in some parts between the tracks and switches. For example, in figure 8-1 related to Avesta Krylbo central station, in the second lower route, several switches connect to each other without any tracks between them. It can be conceived that the software could not establish a distinction between them and created the routes as a true priority. Figure 8-2 shows the schematic map of this part.

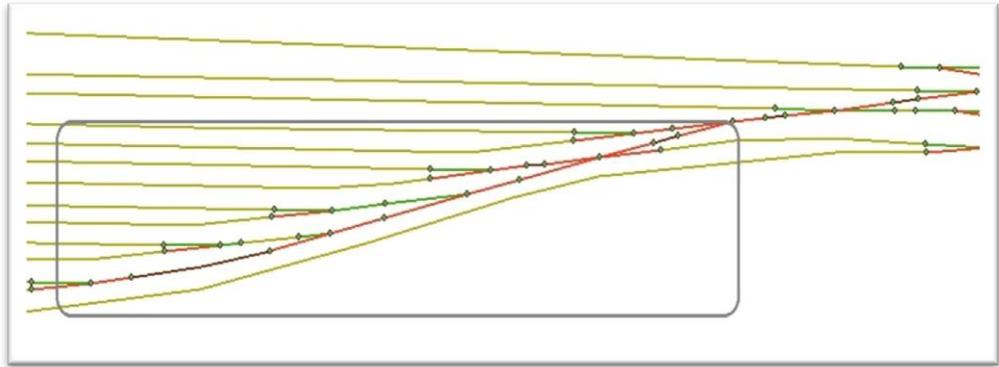


Figure 8-1: The Right side of the geographic view of the Avesta Krylbo central station with a lot of switches connected to each other without any tracks between them.

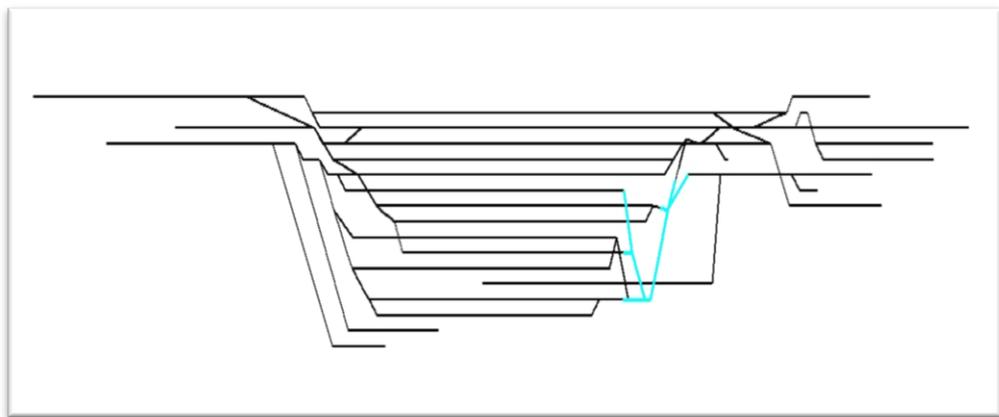


Figure 8-2: The schematic view of the Avesta Krylbo central station with a lot of switches connected to each other without any tracks between them.

It is asserted that after some manual editing, which is explained in section 7-2, the right position of the tracks should be the same as figure 8-3:

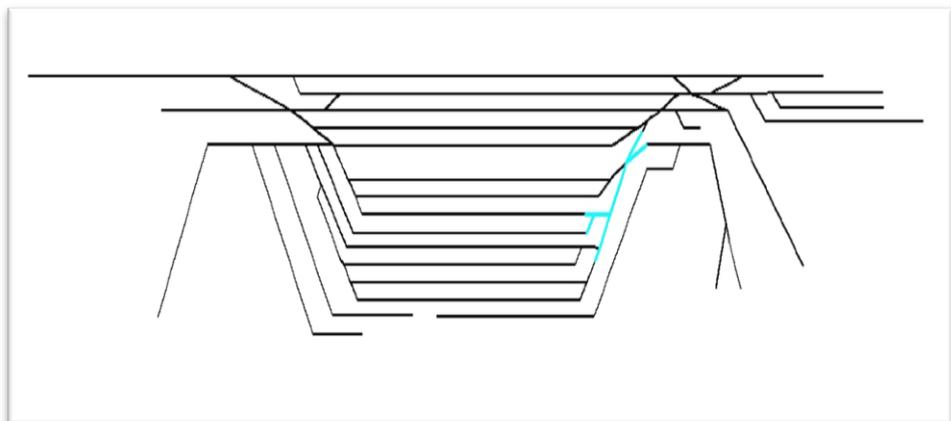


Figure 8-3: The schematic view of the Avesta Krylbo central station with a lot of switches connected to each other without any tracks between them (After manual editing).

Consequently, it can be inferred that this inability to distinguish the level of the switches in some special connections could be a weakness of the software, such as in the obtained result in Avesta Krylbo central station. Therefore, it moved some of the junctions and lines up or down. Therefore, the topology map regarding different connections must be improved so that the logical connections represent reality.

Even with this weakness, the original output of ArcGIS Schematics extension is acceptable for Trafikverket since even with the manual editing required to adjust the output of ArcGIS Schematics, the overall time investment is still much less than to create a completely manual map in BIS. For example, for Lund central station it takes around one hour, or for Malmö central station around one and one and half hour. While in BIS, the user needs to work on it for more than two days.

Another problem with ArcGIS Schematics is that the algorithm behind the program is not published, i.e. it works as a black box system. In comparing the main steps in ArcGIS Schematics extension for creating the schematic maps and the algorithms in different articles (section 3.4), it seems that the algorithm for creating the schematic map in ArcGIS Schematics extension is similar to the algorithm that Cabello et al. (2004) presented in their paper. In both Cabello et al. (2004) and ArcGIS Schematics extension methods, similar input data are used, and there are similar parameter settings such as defining ordering number for lines in the schematic map and defined the vertical distance between lines. Finally, as Cabello et al. (2004) do some extra editing according to the aesthetic point of view on their algorithm, in ArcGIS Schematics extension we also need to do some manual editing.

9. Concluding Remarks

9.1. Conclusions

In this study, the current data from Trafikverket were evaluated as suitable input for ArcGIS Schematics. Trafikverket found that since their data in BIS and new information model include information about the network, it can be matched and be considered as suitable input data for the schematic extension. Nonetheless, as it was mentioned in section 7-4, their data needs to be revised and a new feature type (Line_Type) added to them. After these adjustments, the data could be used for the ArcGIS Schematics extension. In addition, the geometric network needs to be created by applying the RefLinkPart data (the tracks information data) and the Spårväxel data (the switches information data). Moreover, maintaining the topology is also important.

Since the algorithm behind the ArcGIS program is not published, different articles were reviewed, and by comparing the main steps in ArcGIS Schematics extension for creating the schematic maps and the algorithms in these articles, it seems that the algorithm in ArcGIS Schematics extension is similar to the algorithm that Cabello et al. (2004) presented in their paper. Both software and Cabello et al. (2004) method define similar parameter settings and ordering for positioning lines in the schematic maps. At the end of creating schematic maps, similar to Cabello et al. (2004) who do some extra editing according to the aesthetic point of view on their algorithm in ArcGIS Schematics extension we also need to do some manual editing.

By examining different methods for automatically generating schematic maps from a geographic database, it seems that Trafikverket's information model is suitable for railway applications. This objective of the project was fulfilled by examining different data and feature classes for different central railroad stations while mostly it was focused on the Avesta Krylbo central station and finally the ArcGIS Schematics extension was investigated for Lund and Malmö central stations. It was found that the schematic map from the geographic map in ArcGIS automatically can be generated, while it was intangible for Trafikverket. As of today, they have drawn the schematic map according to what they wanted and they visualized from the shape and the position of the station. Then, according to the

schematic map, they generate the geographic map. Consequently, the ArcGIS Schematics can make it easier to automatically create and update the schematic map.

It also seems that the ArcGIS Schematic meets the requirements of the railway network which are provided by Trafikverket. The results show that this extension is useful for them and they can automatically generate the schematic maps with their available data. It is matched with their data, but some improvements must be done with their data model. A new feature type (Line_Type: Through or Diverging) must be added to their information model and also their topology maps so that the comparison of the connections to the reality has to be maintained.

Finally, the comparison of our results with the experiences of other European companies (such as ProRail in Holland and RFF in France) shows that they also use ArcGIS Schematics extension for a small part of their network and test it for some stations. Similar to the results in this study, these European companies two separate feature classes must be used, one for tracks and one for the switches. They believe that the Esri algorithm is very useful for a small part of a network not for a complex network. Finally, to have a complete acceptable schematic map for the final users, Trafikverket and these companies find that when using ArcGIS schematics, manual editing must be done in the process to have a nice and acceptable schematic map.

9.2. Suggestions

In summary, to further improve and develop the model for generating schematic maps, some actions must be taken:

- A new feature type (Line_Type) must be added in the information model to the RefLinkPart data as a suitable input for ArcGIS Schematics.
- Another feature class (spårväxel) must be added which it has information about the switches separately.
- Since the RefLinkPart data have the information about the tracks and in the whole network that is expanded, Trafikverket has to erase the location of the switches from it. Therefore, for creating the geometric network, two

separate feature classes can be available, one for the switches and one only for the tracks.

- In addition, Trafikverket has to maintain the topology regarding the true connection to reflect reality.

Consequently, after these improvement and developments of the data model, it is hoped that Trafikverket could easily use the ArcGIS Schematic extension for automatically generating and updating schematic maps from geographic data.

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Appendixes

Appendix 1: The Description of some Parts in UML

- Object: An object represents a feature or an event in the real world. The object can be applied in two meanings; when it is used for data and describes the real object, or when it is used for metadata and describes the data object.
 - Feature: The general concept of feature in this document refers to the elements in rail networks and to the information that is connected to the network.
 - Class: A class is a modeling concept in UML which is used for describing objects types. It is usually an explanation of the real kind of features or objects' characteristics which they share:
 - Attributes, which they describe properties of objects.
 - Relationships, which they are stated between different classes. There are several types of relations which they are briefly explained below.
 - Operations, which they describe the expectation of the class to perform functions that have parameters and return value types.
 - Restrictions, which they complement the UML model by defining different ways to allow or make possible using the model where it is not clearly defined by UML model itself.
- Relations:
- There are several different types of relationship between classes which some of them are described below:
- Inheritance:

The inheritance relationship means that all properties as attributes, relationships and restrictions are inherited from the base class to subclasses. Therefore, substitution is not applicable in this relationship; it means statements concerning the base class apply to any and each one of its subclasses, but the reverse is not applicable. Figure App.1.1 represents

an example of inheritance relationship. In this figure, ExKayak and ExCanadianCanoe are subclasses (specialization) of ExCanoe, and ExCanoe is the base class (generalization).

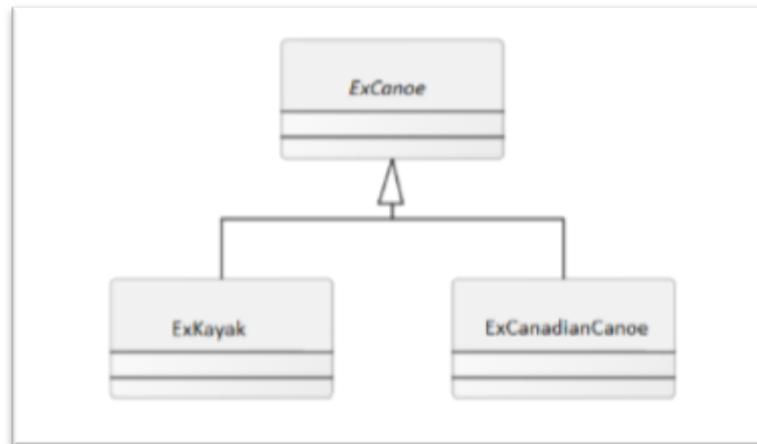


Figure App.1.1: Example of inheritance relationship.

From: (Informationsmodeller, 2013), p. 13

- Association:

An association relationship is specified by a line between classes that are related to each other. An arrow at the end of each direction means that the association is navigable in that direction. The example in figure App.1.2 can be read as:

An ExCompany as an employer may be associated with zero to many ExPerson as employees in the association. Also, an ExPerson is allowed to have zero to many employers.



Figure App.1.2: Example of association relationship.

From: (Informationsmodeller, 2013), p. 14

- Aggregation:
This relationship expresses a stronger association relationship, but it is not used in this information model because the semantics is not completely clear.

- Composition
This relationship also expresses the strongest relationship which is used when it needs to describe an entirety that is built up by its parts and the parts are shared with the entirety. Figure App.1.3 shows a composition between ExEntirety and ExPart, which the entirety consists of or builds up by its parts.

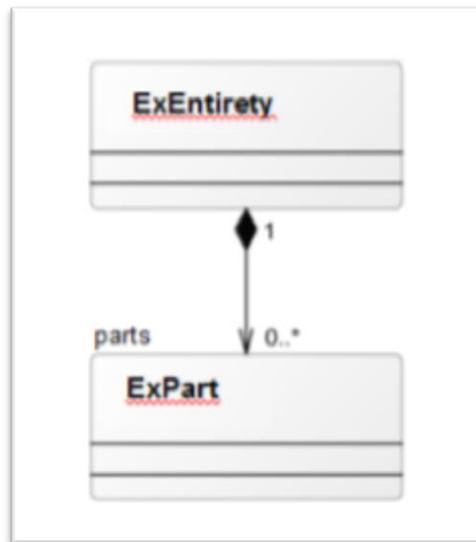


Figure App.1.3: Example of composition relationship.

From: (Informationsmodeller, 2013), p. 15

Appendix 2: Classes and Objects in Transport Network Package

Figure App.2.1 describes different classes that create basic network structure. Also, figure App.2.2 represents the different type of network elements which can be presented in a network. The explanation of these classes and elements are coming in the following.

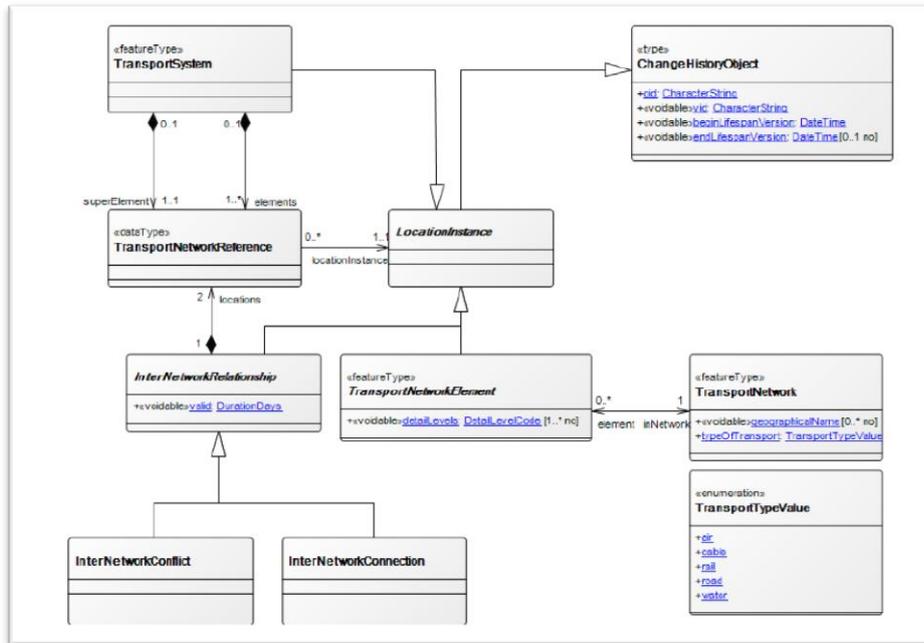


Figure App.2.1: Overall structure of traffic network.

From: (Informationsmodeller, 2013), p. 22

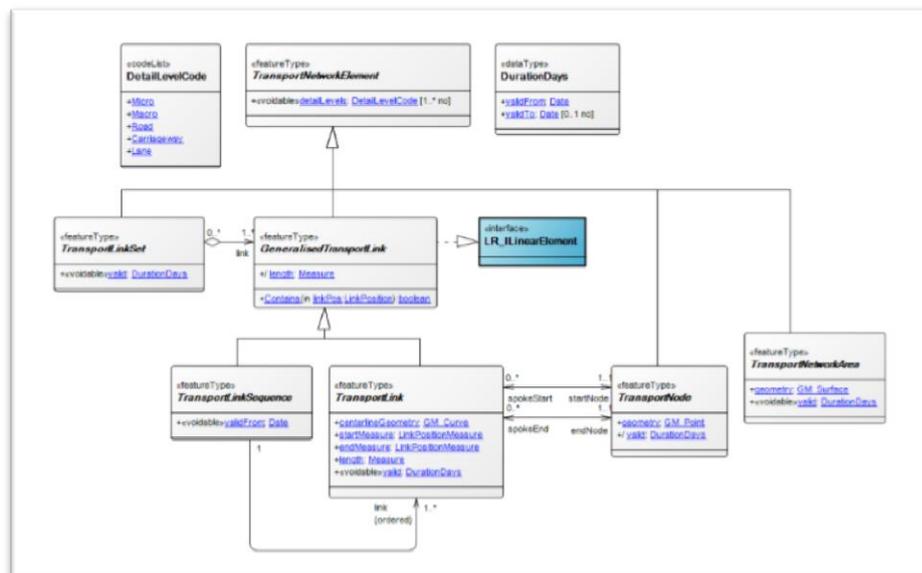


Figure App.2.2: The different types of network elements.

From: (Informationsmodeller, 2013), p. 23

- TransportNetwork: This class denotes a set of topologically interconnected network elements (TransportNetworkElement) for a transport type.
- LocationInstance: It is an abstract base class for position objects. This class is a subclass of ChangeHistoryObject. It means that it is a subject to change management
- TransportNetworkElement: It is an abstract base class that denotes an element in a network. It is also a subclass of LocationInstance which it means that each element is a position object for possible connect features, and that element is subject for changing management.
- InterNetworkRelationship: It is an abstract base class for describing relationships between elements in different networks.
- InterNetworkConflict: It is a type of InterNetworkRelationship for describing conflicts between different networks, either within or between different transport types.
- InterNetworkConnection: It is a type of InterNetworkRelationship for describing relationships between network elements in different networks with the same type of transportation.
- TransportSystem: It is a grouping of elements which it is considered as a network element with less detailed level.
- TransportNetworkReference: It is a concrete base class for all types of connections in the network.
- TransportTypeValue: It is a class as an enumeration for possible types of transportations.
- TransportNode: It is a type of network elements which is used for representing a specific position in the network. A node is an abstract base class which always locates at the beginning or end of a link.
- TransportLink / RefLinkPart: It is a type of linear network element which is used for connecting two nodes. It is an abstract base class. The direction of a link is always positive from its start node to its end node, and it should be constant with the direction of its geometry.
- TransportLinkSequence / RefLink: It is also a type of linear transport network element which is used for describing a sequence of transport link. This element is an abstract base class. A link sequence can pass through one or more nodes, but if

two links are connected to a node, one link should be incoming and the other one should be outgoing.

- TransportLinkSet: It is a type of network element which includes a set of linear elements (links or link sequences), where the set as a complete part has a specific purpose in the network. The TransportLinkSet element is an abstract base class.
- GeneralisedTransportLink: It is a linear network element (realizes interface LR_ILinearElement) which is used as a target for linear references. Therefore, it must fulfill requirements for describing a single continuous path in the network. The GeneralisedTransportLink element is an abstract base class.
- TransportNetworkArea: It is used for representing a two-dimensional network element. A TransportNetworkArea element is an abstract base class.
- DurationDays: It is a class for describing a data type to specify the time period with resolution in days. The class is used for many classes in transport network package to describe validity.
- DetailLevelCode: It is an enumeration of valid level of details.

Appendix 3: Classes and Objects in Transport Network Reference Package

Figure App.3.1 shows a basic type of the transport network reference package, the details of different classes in this package are as following:

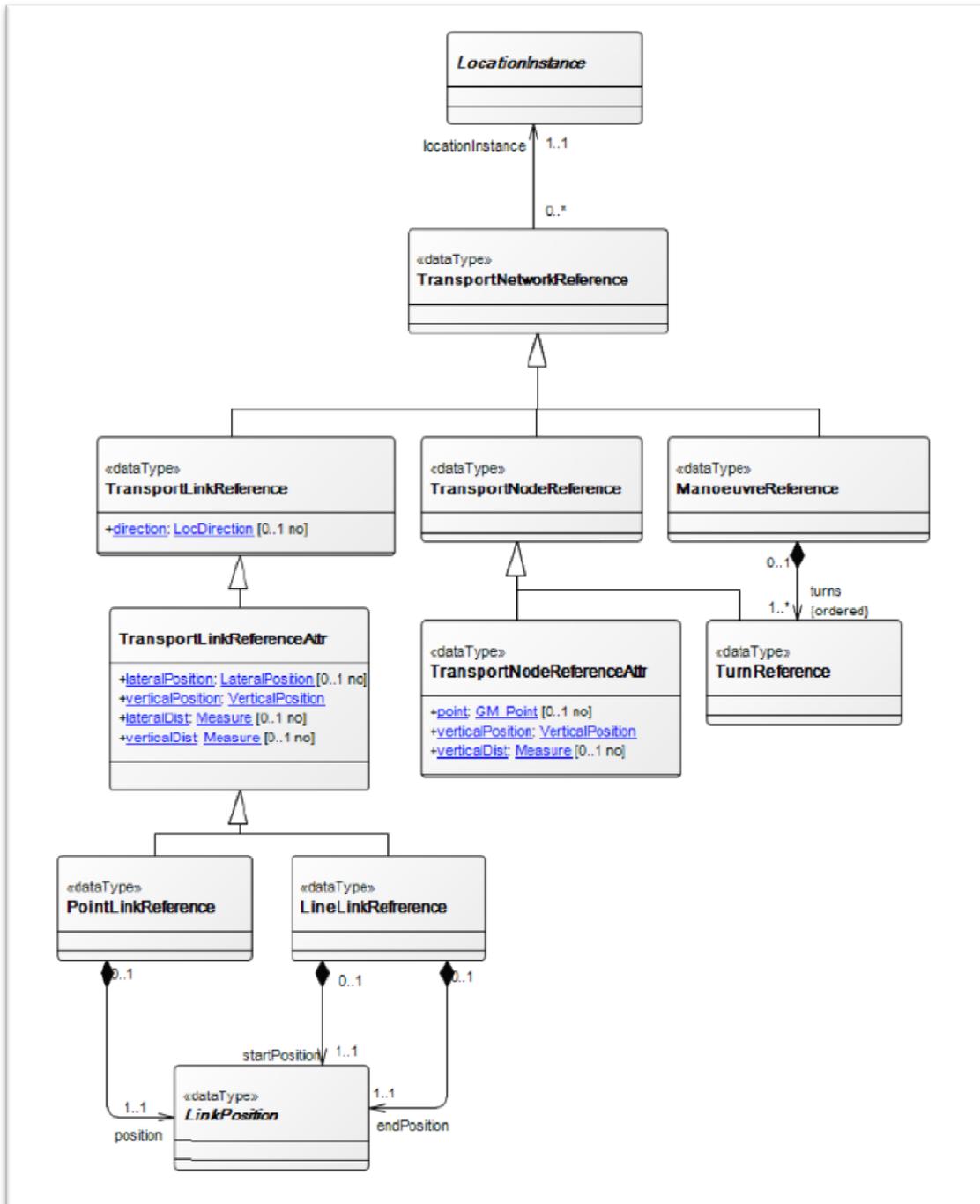


Figure App.3.1: Transport network reference, basic type.

From: (Informationsmodeller, 2013), p. 53

- TransportLinkReference: It is a base class in the network for network connection to linear elements (GeneralisedTransportLink). The Referenced position object should be a type of GeneralisedTransportLink or any of its subclasses.
- TransportLinkReferenceAttr: It is a base class in the network for network connection to linear elements (GeneralisedTransportLink).
- PointLinkReference: It is a subclass to TransportLinkReferenceAttr for representing location of points on linear elements in the network (GeneralisedTransportLink). The attribute can be different based on the indication of link position (LinkPosition).
- LineLinkReference: It is a subclass to LinkReference for defining the position in linear elements in the network in the form of a distance (GeneralisedTransportLink).
- TransportNodeReference: It is a base class for specifying location of a node in the network. It is also a subclass for TransportNetworkReference.
- TransportNodeReferenceAttr: It is a subclass to TransportNodeReference for defining position of nodes in the network which is not turn. The class is used for connecting a specify location to a node.
- TurnReference: It is a class for defining turn through a node.
- ManoeuvreReference: It is a class for defining a maneuver. Maneuver is a term of turns where each turn on the network element has a to-position the same as the from-position for the following turn.

Appendix 4: Classes and Objects in Railway Transport Network Package

Figure App.4.1 shows different classes in the railway transport network package. The details of different classes in this package are as following:

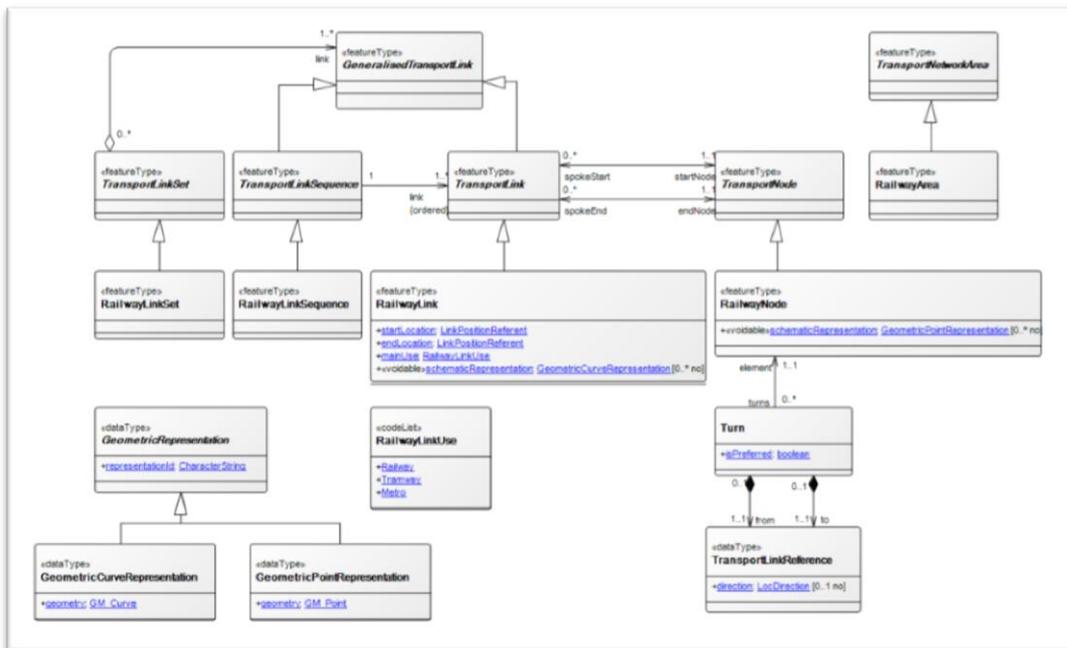


Figure App.4.1: Railway transport network overview.

From: (Informationsmodeller, 2013), p. 88

- RailwayLinkSet: It is a subclass of TransportLinkSet for describing related set of rail links and rail link arrangements according to their role in the railway network.
- RailwayLinkSequence: It is a subtype of TransportLinkSequence proposed for railway.
- RailwayLink: It is a subtype of TransportLink proposed for railway.
- RailwayNode: It is a subtype of TransportNode proposed for railway. Since a railway node originally cannot be used for navigation, each possibility to travel through the node is stated and defined by a turn option (Class Turn).
- GeometricRepresentation: It is an abstract base class for representing different geometrical types.

- GeometricCurveRepresentation: It is a class for representing geometrical lines. It is a subclass of GeometricRepresentation.
- GeometricPointRepresentation: It is a class for representing geometrical points. It is a subclass of GeometricRepresentation.
 - RailwayArea: It is a subclass of TransportNetworkArea for describing an area of railway network.
 - Turn: It is a class for describing a turn option for railway, such as travelling through a railway switch. The turn always defines in a certain direction like from-via-to.
 - RailwayLinkUse: It is a class for enumerating the possible values for the primary usage of the track.

Appendix 5: Questionnaire to other Railroad Administrations in Europe

If you use schematics representation:

- How does your data model look, how do you represent your switches and nodes?
- How you represent your model as a schematic representation?
- How much you can control the outlook of schematic representation?
- Do the users accept the outlook of the representation?
- Which software/applications do you use or have tested for schematic representation?

Do you use ArcGIS? If yes:

- Do you use it just for creating the real map or just for testing the ArcGIS Schematic?
- Which are the key benefits of the application?
- Which obstacles have you encountered with the application?
- Have you solved the problem with saving schematic in ArcGIS?
- If you use ArcGIS for testing the ArcGIS Schematics, what do you find about it:
 - o How is its performance, its ability, and etc.?
 - o Do you reject it or accept it?

Appendix 6: Detail of Creating Schematic Maps in ArcCatalog Tab and ArcMap

In ArcCatalog Tab:

- Creating a File Geodataset for each central station by right-click on the main folder in the Catalog tree and chose *New > File Geodatabase* from the pop-up menu.
- Creating a New Feature Dataset in each Geodatabase by right-click on the Geodatabase in the Catalog tree and chose *New > Feature Dataset* from the pop-up menu.
- After copying input data (RefLinkPart data+ Spårväxel data) in the Feature Dataset create Geometric Network by right-click on the Feature Dataset in the Catalog tree and chose *New > Geometric Network* from the pop-up menu.
- Also by right-click on the Geodataset in the Catalog tree and choosing *New > Schematic dataset* from the pop-up menu, create the Schematic Dataset.
- By right-click on the Schematic Dataset and choosing *Edit* from the pop-up menu,

After starting the Schematic Dataset editor application:

- o Right-click on the schematic dataset entry in the Schematic Dataset Editor tree and chose *New Schematic Diagram Template* from the pop-up menu.
- o Use Properties tab and wrote a name for the *Name* field (figure App.6.1).

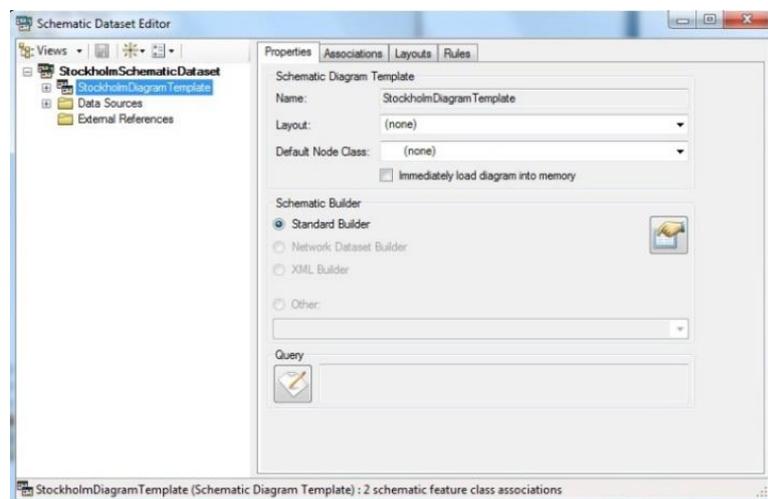


Figure App.6.1: Schematic Dataset Editor Dialog box.

- Right-click on the template file and chose Import From Feature Layers from the pop-up menu. Then *Import From Feature Layers* dialog box was opened.
- By clicking the ellipse button at the end of the *Map or Layer File* input area, “*Select A Map Or Layer File To Import*” dialog box was opened, and by navigating to select the intended .mxd file, the selected feature layers were imported to the desired schematic diagram template (figure App.6.2).

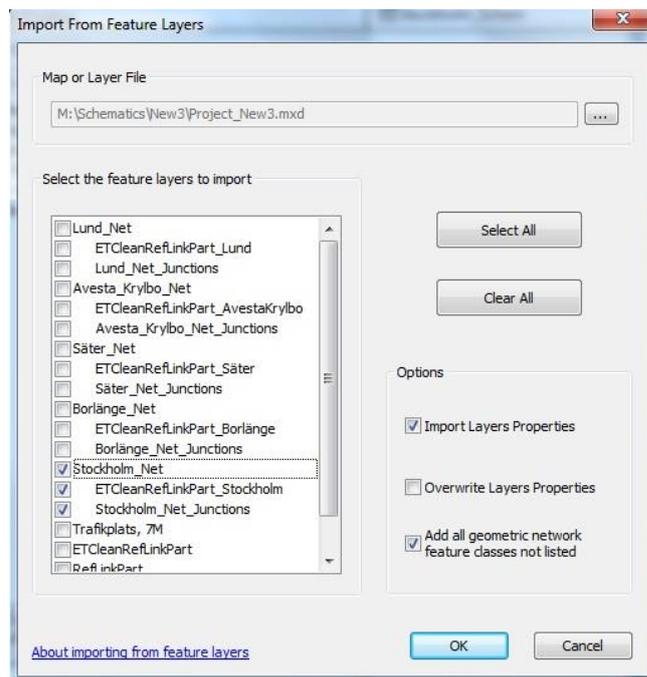


Figure App.6.2: Import From Feature Layers dialog box.

By saving the Schematic Dataset Editor Toolbar, a Schematic dataset is configured, and then it was ready to be applied for creating schematic diagrams in ArcMap. At this instant, ArcMap can be started and the intended .mxd file is opened. For creating the schematic map, the following workflow in ArcMap must be done:

In ArcMap:

- Select features that it is needed the schematic maps are created for them.
- Clicked *Generate New Schematic Diagram* Button.
New Schematic Diagram dialog box was opened.
- Clicked browse button next to the *Schematic Dataset or Folder* text box to specify the schematic dataset in which the schematic diagram was going to be stored.
- Clicked *Schematic Diagram Template* drop-down arrow and chose the desired schematic diagram template from the list.
- Keep the default *[Create New Data Frame]* option selected in the Output Data Frame dropdown list.
- Typed a name in the *Schematic Diagram Name* text box for the diagram to be generated.
- In the *Input From* area, the option selected must be kept and make sure that the Geography data frame contains the selection set they had just created was selected in the drop-down list (figure App.6.3).

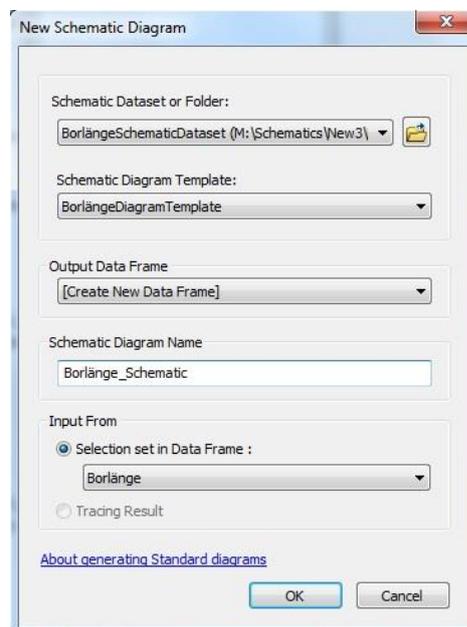


Figure App.6.3: New Schematic Diagram dialog box.

By clicking OK button, the diagram generation is started and the result of the schematic diagram is displayed.

For changing the layout, at first the Relative Main Line algorithm must be selected in the Layout Task. Then these setting must be done in the layout task properties (figure App.6.4):

- Select ROUTE_ID as the attribute name,
- Check the Use a line type attribute box, Line_Type as name, Through as main line value, and Diverging as excluded value.
- Check the Use a priority attribute box and select the PRIORITY as name.
- Select a suitable value for offset between branches and the break points angle.
- Set other selection according to the demand.

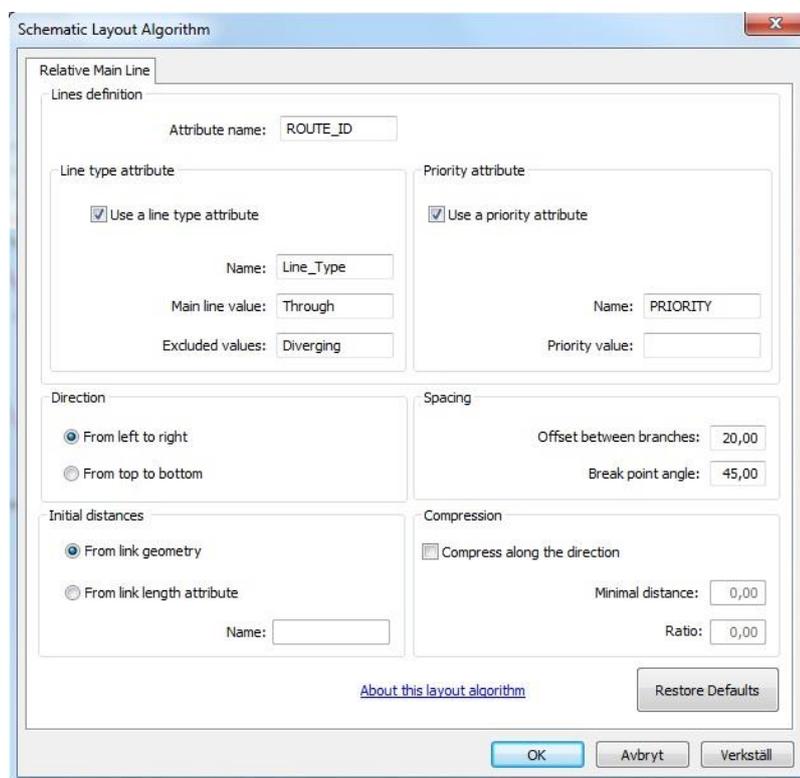


Figure App.6.4: Schematic Layout Algorithm Properties.

After doing these settings, use *Set Schematic Root*  tools for specifying root schematic nodes, so the hierarchical layout starts with the specified root schematic node. Then by click *Apply Layout Task* button  to apply the selected schematic layout task, the schematic diagram becomes active.

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